KIAPS Next Generation Global Model

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- Overview of KIAPS
- Dynamical core
- Physics
- Data assimilation
- System optimization
- Verification

Overview of KIAPS

❒ **Purpose** : Developing a next generation global operational modeling for KMA

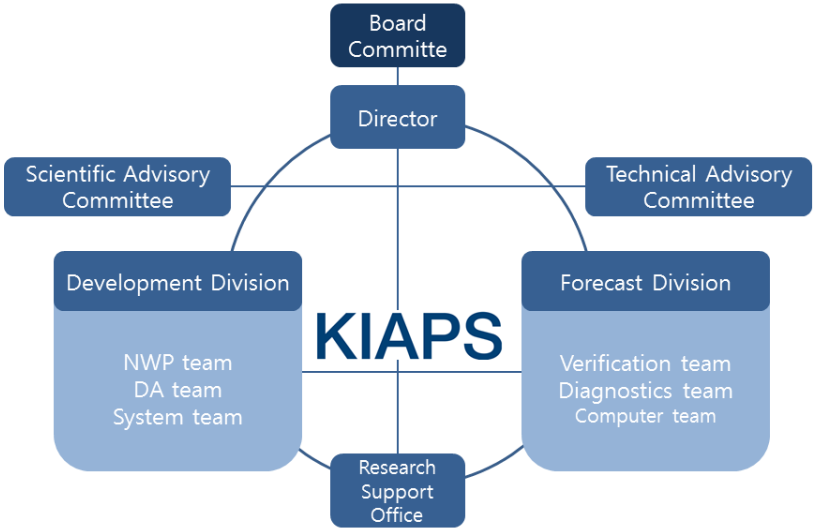
❒ **Project period** : 2011~2019(toal 9 years)

❒ **Total Budget**: $95 million

2015 budget -$8.5 million

❒ **KIAPS is founded at Feb. 15th 2011**

- organization: 2divisions, 6teams, 1office
- Man power: 55/58



Total	Director	Research Staff			Administrative staff		
		Principal Researcher	Senior Researcher	Researcher	Principal Staff	Senior Staff	Staff
55	1	12	25	11		3	3

Three-stage development plan of KIAPS Global Model

step1

Foundation and basic research

- Establish the foundation of KIAPS research and development environment
- Efforts on laying out future model development – model dynamics, physics and data assimilation

2011-2013

step2

Release beta version

- Complete developing major model components based on KIAPS own research
- Release the KIAPS beta version model
- conduct semi realtime experiments with KIAPS beta version and evaluate it skills to the KMA operational model

2014-2016

step3

Finalize the operational system

- Finalize the KIAPS operational version 1.0 and run on semi-operational basis
- Stabilize the model system by further diagnostics and verifications
- Release the KIAPS system to international users

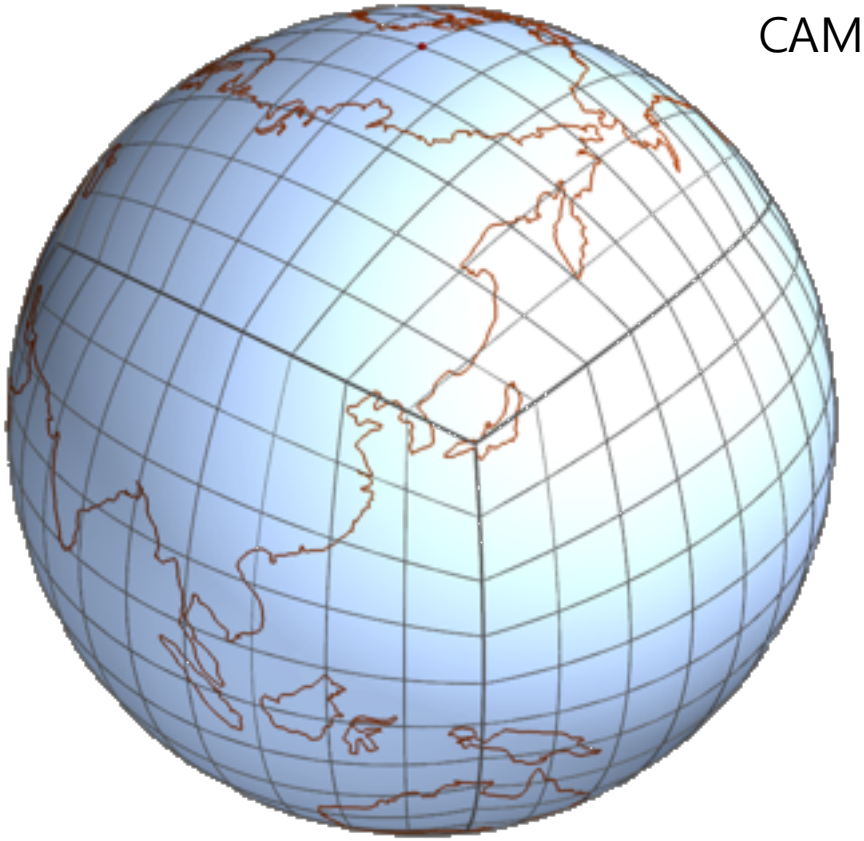
2017-2019

Development of dynamic core

Dynamic core of KIM (KIAPS Integrated Model)

	KIM-SH **(High Order Method Modeling Environment model; NCAR's CAM-SE)**	**KIM-SW** **(Kiaps Integrated Model – Spectral element method, WRF-Type)**
Spherical grid	Cubed-sphere (Equi-angular gnomonic projection)	
Horizontal approximation	Spectral Element	
Vertical approximation	Finite Element	Finite Difference
Temporal approximation	Fully Explicit Leapfrog, first-order due to Robert-Asselin filter	Split-explicit RK3, second-order for nonlinear equation
Equation	Hydrostatic (Full variables)	Non-hydrostatic (Perturbation variables)
Explicit spatial diffusion	4^{th} order linear horizontal diffusion	6^{th} order horizontal diffusion + divergence damping

KIM (KIAPS Integrated Model)



Hydrostatic/Non-hydrostatic system with spectral element method over cubed sphere grid (as in CAM-SE)

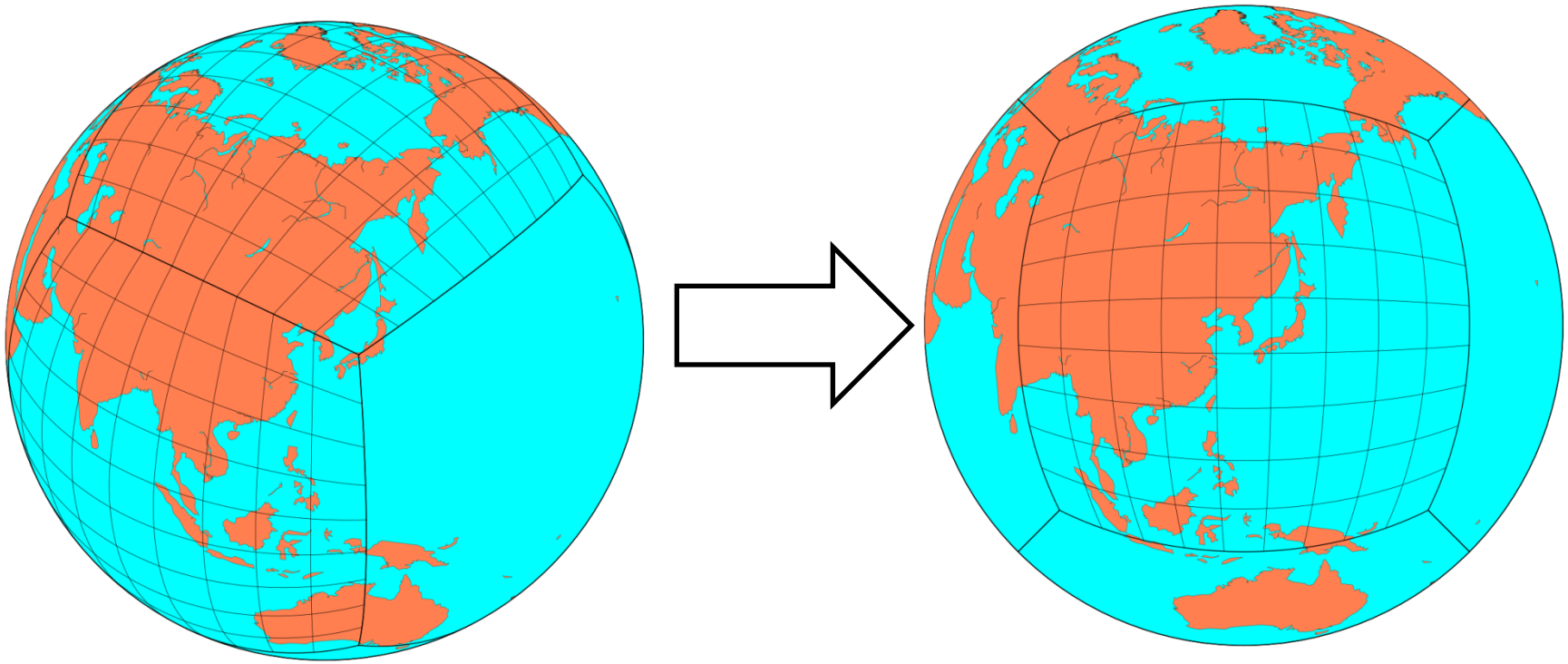
Advantage:

1. Avoid pole singularity
2. Better scalability

Disadvantage

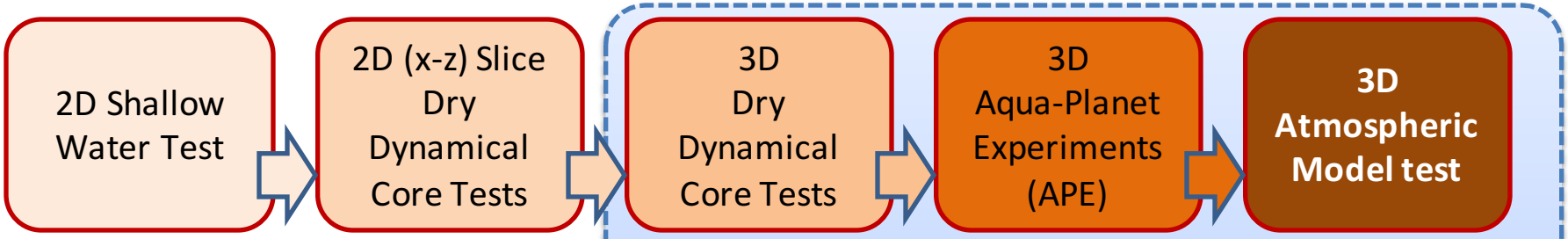
1. Grid imprinting
2. Non-conservative

Rotation of Cubed Sphere



Development of Non-hydrostatic Dyn.

- **KIM-SW (based on WRF governing equations)**
  - Cubed sphere, horizontal: Spectral element, vertical: FD, terrain-following
  - Flux-type compressible governing equations in perturbation form with prognostic variables
  - Time-split time integration: Slow mode → third-order Runge-Kutta
    Horizontal sound wave and gravity wave → Forward-Backward
    vertical sound wave and buoyancy → implicit



1. Advection of cosine bell
2. Steady state
3. Translating low
4. Zonal flow over an isolated mountain
5. Rossby-Haurwitz wave

1. Linear hydrostatic mountain wave
2. Simulations The Schar-type mtn.
3. Density current
4. Inertial-gravity wave
5. Rising thermal bubble

(Choi et al., 2014)

1. Steady-sate
2. Baroclinic wave
3. 3D Rossby-Haurwaitz wave
4. Mountain-induced Rossby wave
5. Pure gravity wave
6. DCMIP pure advection test
7. *DCMIP Mountain-wave over a Schar-type*
8. Held-Suarez

1. Control APE
2. 3KW1 APE

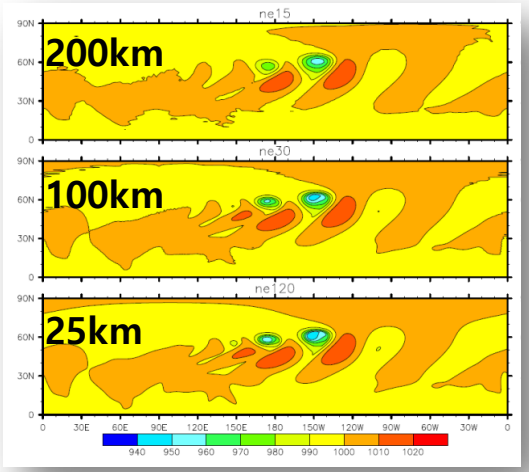
1. *the 5-case for a severe weather*

2015

(Choi and Hong, 2015)

Development of Non-hydrostatic Dyn.

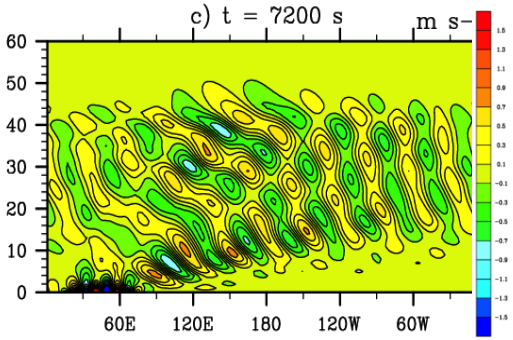
Baroclinic instability, Ps (9-days)



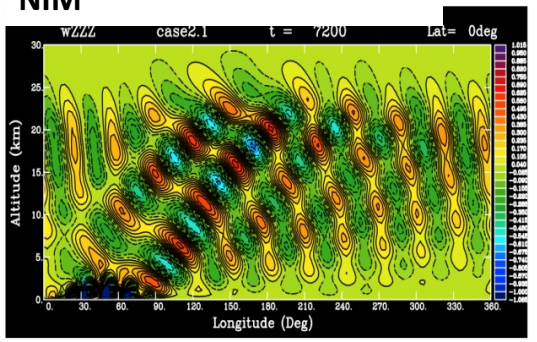
RMSD of global Ps

Schär mountain gravity wave in reduced Earth (X=500)

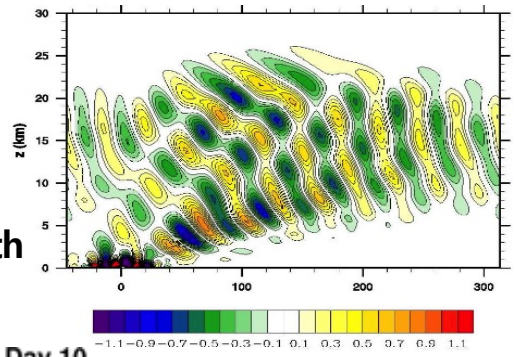
ENDGame



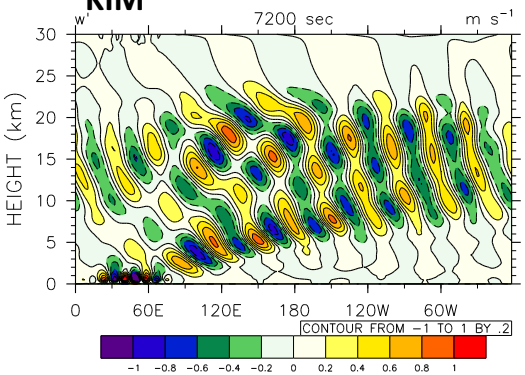
NIM



MPAS

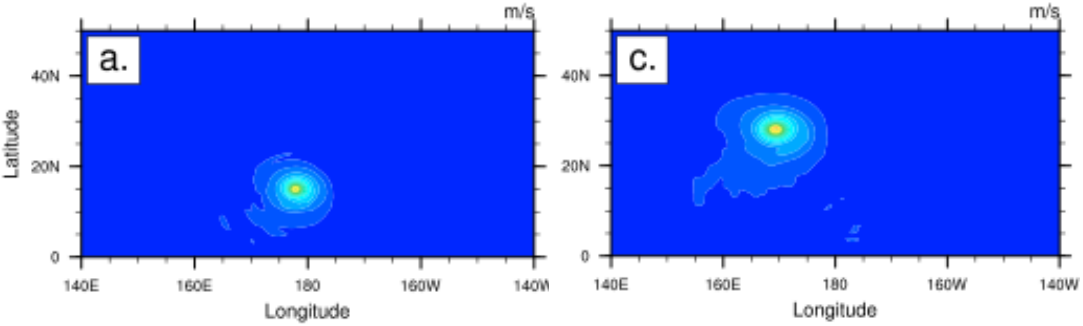


KIM



- **Idealized tropical cyclone with simplified physical forcings**

Day 3 **Day 10**

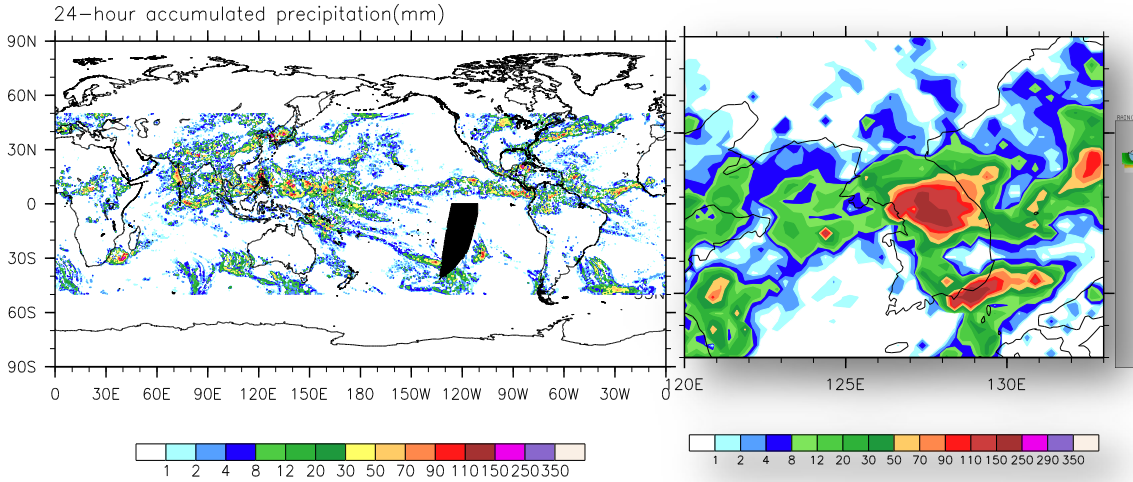


https://www.earthsystemcog.org/projects/dcmip-2012/Test_Cases/results_by_r

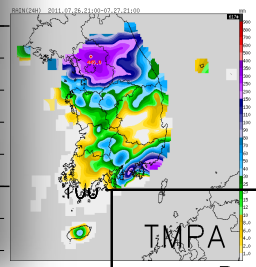
Development of Non-hydrostatic Dyn.

Heavy rainfall case over the Korea peninsula: 24hr accumulated precipitation (24-48hr, ~25km)

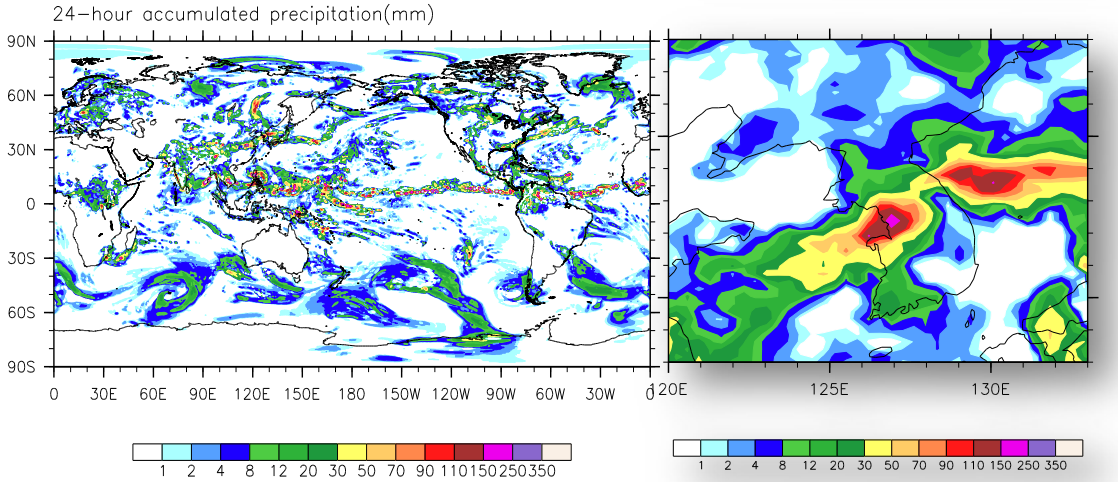
TMPA

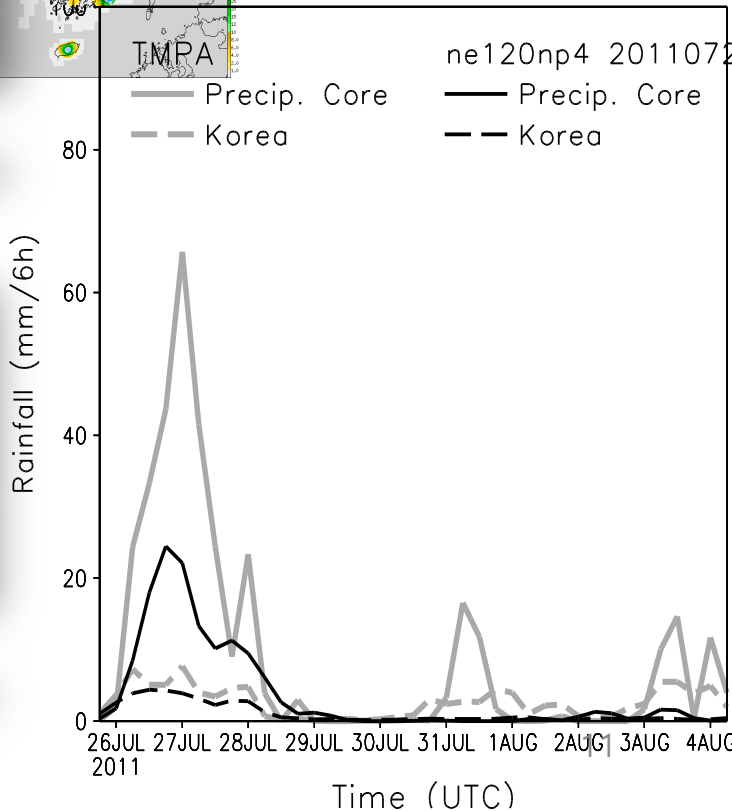


AWS



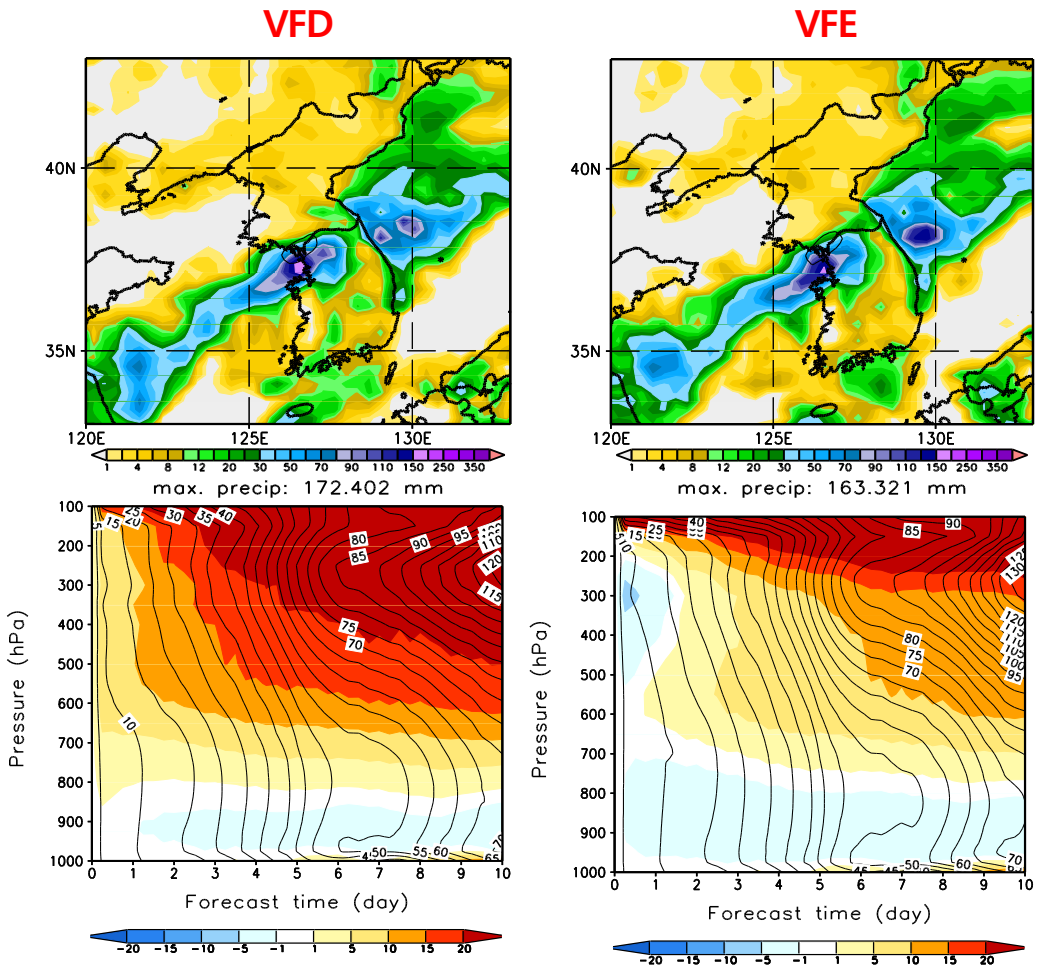
KIM-SW

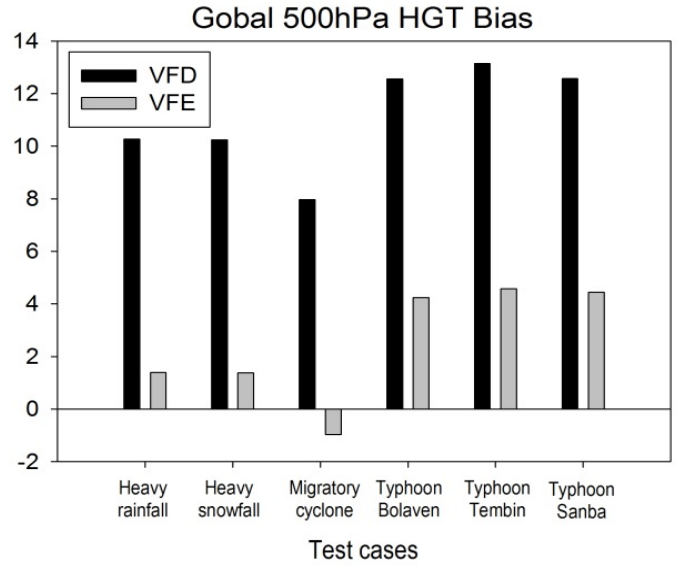


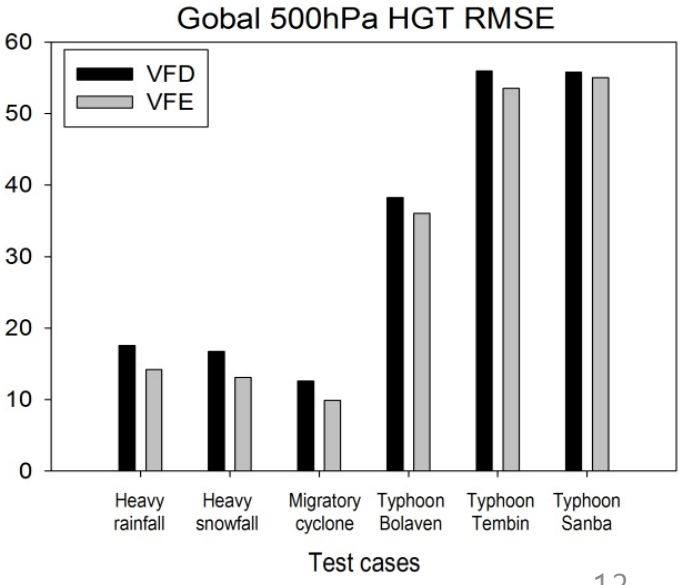


Development of Advanced Dynamical Core

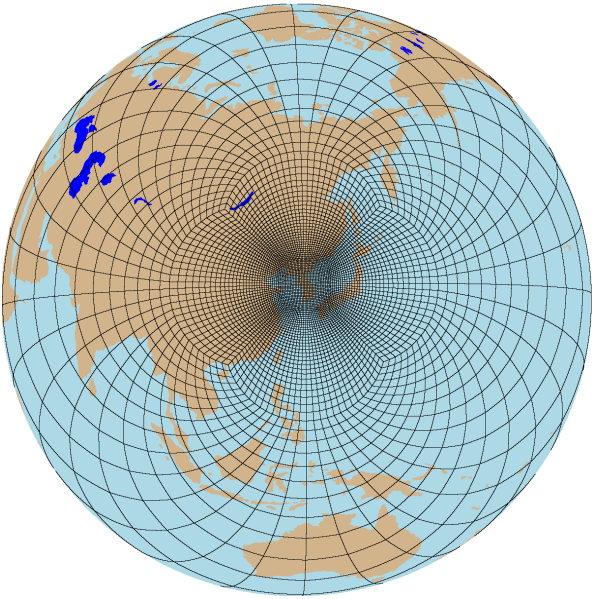
- **Vertical finite difference → vertical finite element**
  - More accurate than VFD
  - The level of computational mode may be reduced

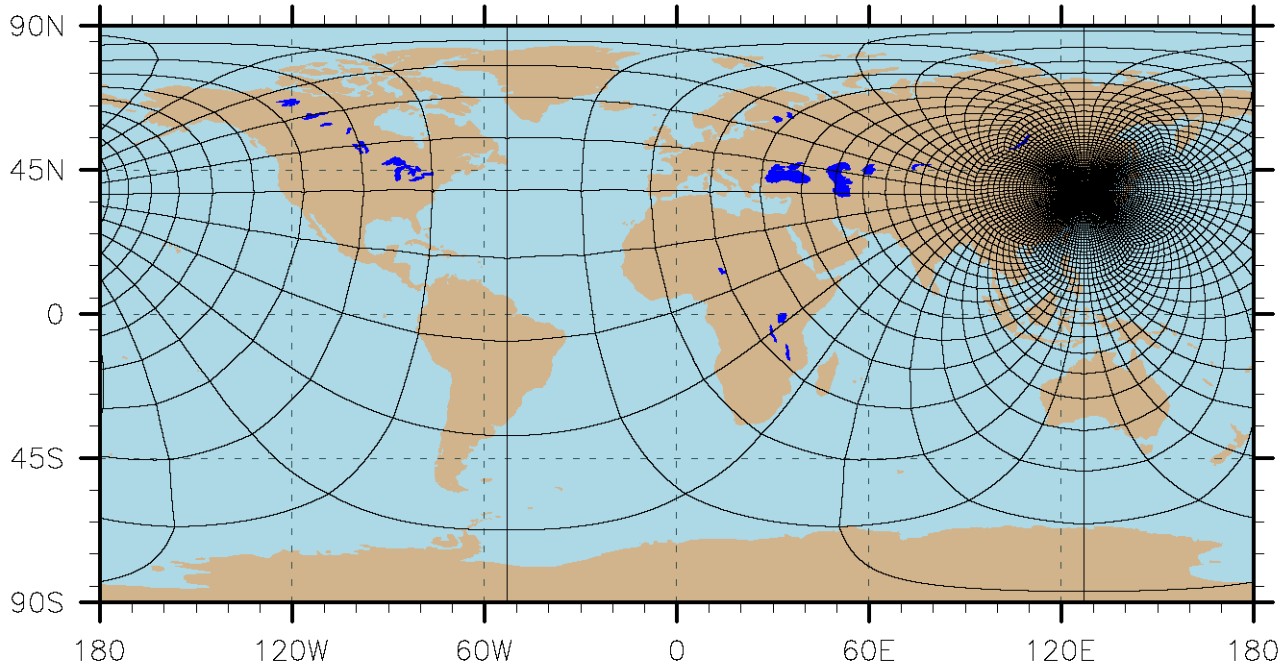






Exploring variable resolution KIM
(e.g. 3km around Korea)





Development of physics

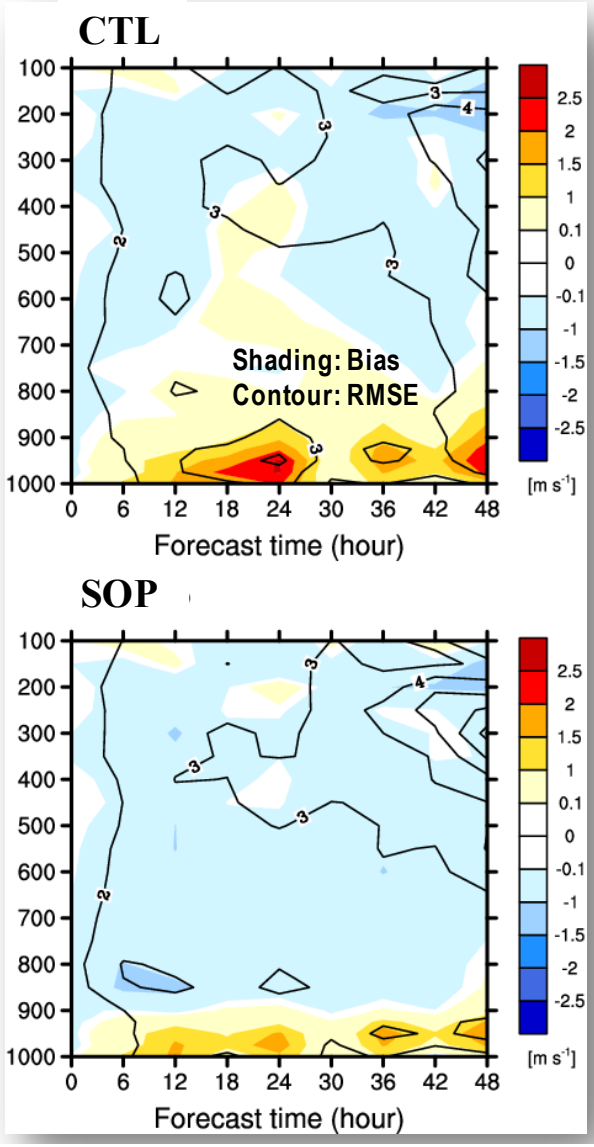
Physics upgrades (1.0: 201402 2.2: 201601 2.4:20160701)

	KIM1.0 (1단계)	KIM2.2 (2016. 1. 1.)	KIM2.4 (2016. 7. 1., plan)
Radiation	RRTMG	RRTMG+new aerosol climatology/surface albedo and emissivity	RRTMG+new aerosol climatology/surface albedo and emissivity+code clean-up+new snow albedo+cloud overlaping
Convection	deep: SAS (Han and Pan, 2011) shallow: Han and Pan (2011)	deep: SAS + scale-aware + autoconversion shallow: Hong et al. (2013)+eddy diffusivity profile	deep: SAS + scale-aware + autoconversion + diurnal variation shallow: Hong et al. (2013)+eddy diffusivity profile 개선
Microphysics	WSM6 (Hong and Lim, 2006)	WSM5 (Hong et al. 2004) + effective radius	WSM5 (Hong et al. 2004) + effective radius+Partial cloudiness
Cloudiness	Wilson and Gregory (2003)	prognostic cloudiness (Park et al., 2016) + CPS cloud fraction effect	prognostic cloudiness (Park et al., 2016) + CPS cloud fraction 산출방법 개선
Orographic GWD	McFarlane (1987)	Kim-Arakawa (Hong et al. 2008) + flow-blocking drag + orographic anisotropy	Kim-Arakawa 방안 (Hong et al. 2008) + flow-blocking drag + orographic anisotropy+improve tress
Non-orographic GWD	Warner and McIntyre (2001)	Chun and Baik (1998) (Jeon et al. 2010)	Chun and Baik (1998) 기반 대류중력파 방안 (Jeon et al. 2010)+non-stationary GWD
LSM	Noah v2.5 LSM	Noah v3.0 LSM+ 3-layer sea-ice model + MOSAIC	Noah v3.0 지면모델 + 3-layer sea-ice model + MOSAIC+ verification
PBL	YSU	YSU + top-down mixing	YSU + top-down mixing+scale –aware

GWDO

Advanced Physics

Wind speed (3-5 Jan. 2010)



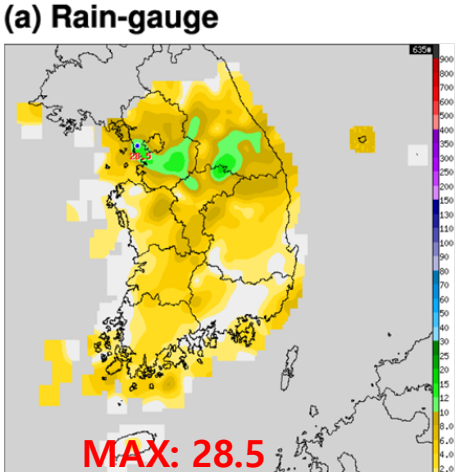
Flow-blocking drag → Improved wind

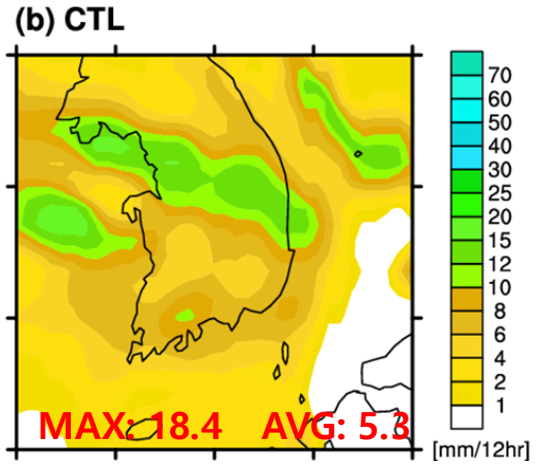
Heavy snowfall event (18UTC03-06UTC04 Jan. 2010)

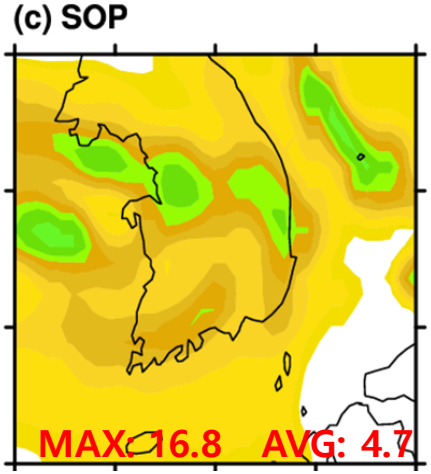
CTL:
(Hong et al. 2008, WF)

↓

SOP:
(**Orographic anisotropy + flow-blocking drag**)
(Choi and Hong 2015, JGR)







Weakened low-level wind speed →reduced heat fluxes
→ Improved snowfall overestimation over Korea

Choi and Hong (2015)

Prognostic Cloudiness

Advanced Physics

Diagnostic cloud fraction (Xu and Randall, 1996)

$$C_s = RH^P \left[1 - \exp\left(-\alpha_0 \bar{q}_l \Big/ \left[(1-RH)q^*\right]^\gamma\right)\right]$$

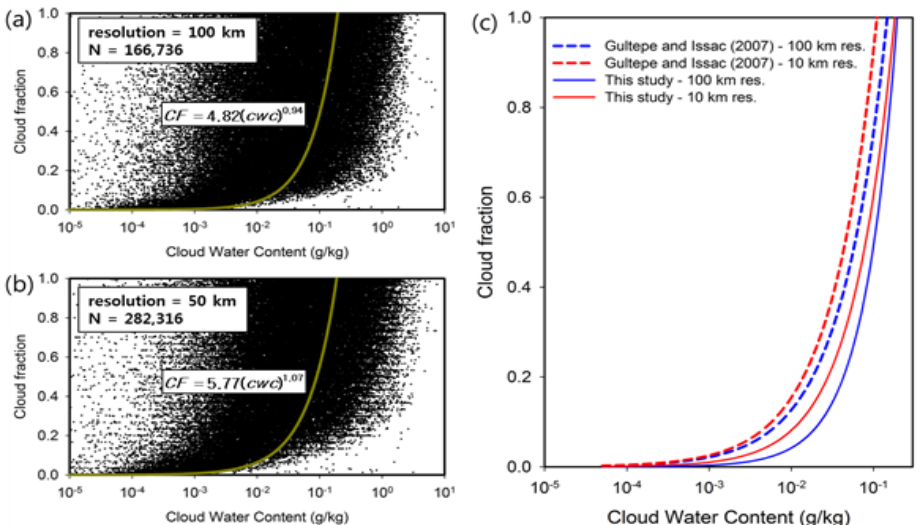
Prognostic cloud fraction (Tiedtke, 1993)

$$\frac{\partial a}{\partial t} = A(a) + S(a)_{CV} + S(a)_{BL} + S(a)_C - D(a)$$

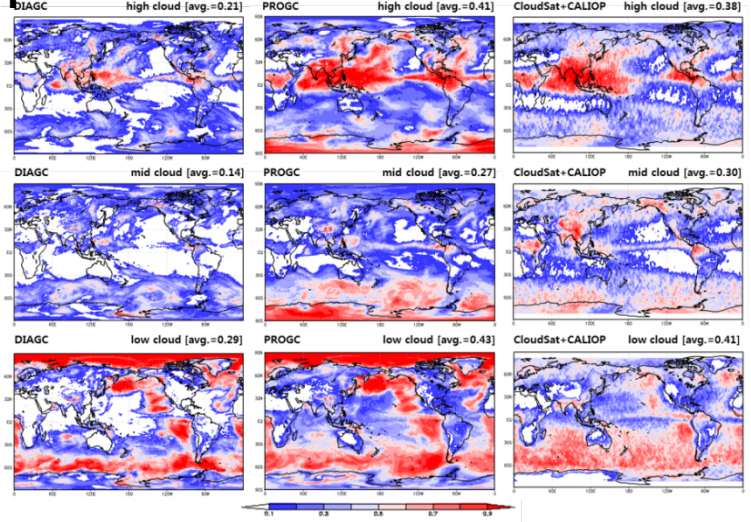
Improvement of prognostic cloud fraction (PROGC)

$$C_{L\alpha} = \frac{1}{50}\left\{5.77(100 - L_\alpha)q_{c,L\alpha}^{1.07} + 4.82(L_\alpha - 50)q_{c,L\alpha}^{0.94}\right\}$$

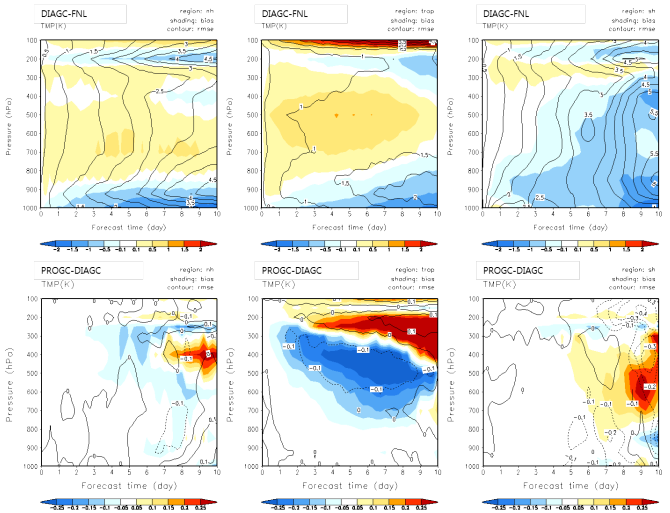
Relation between cloud water and cloud fraction by cumulus convection



Improvement of cloud fraction via PROGC



Improvement of NWP performance via PROGC



Park et al. (2016)

☐ The grid-size dependency is considered (scale-aware scheme)

$$\sigma = 1 - \frac{1}{\pi}\left\{\tan^{-1}\left[\sigma_{con}\left(\Delta x - \Delta x_{5km}\right)\right] + \frac{\pi}{2}\right\}$$

where $\sigma_{con} = \dfrac{\tan(0.4\pi)}{\Delta x_{5km} - \Delta x_{1km}}$

Adapted from Hong and Pan (1998, MWR)

Δx	σ
9 km	0.1
5 km	0.5
1 km	0.9

- **Cloud-base mass flux** [∝ $(1 - \sigma)^2$]
- **Convective Inhibition** (∝ (1-σ))
- **Moisture detrained to grid scale** (∝ σ)

Convective strength is negatively proportional to convective fractional area (CFA)

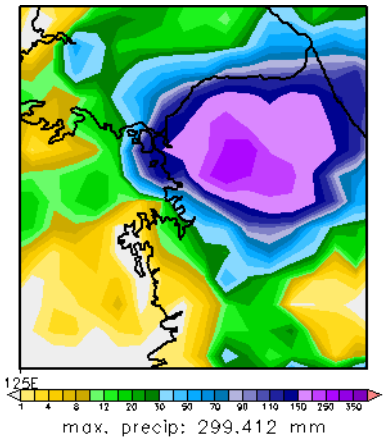
Convection trigger is negatively proportional to CFA

Convective detrainment of hydrometeor is positively proportional to CFA

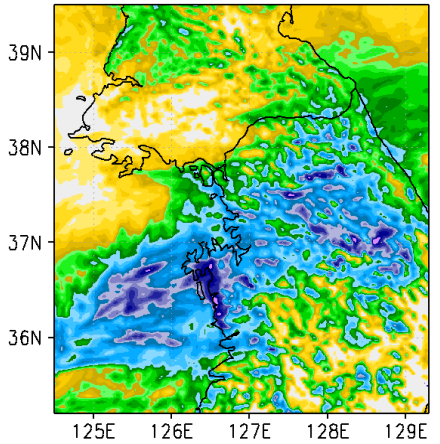
Submitted to MWR (Kwon and Hong)

24-h accumulated precipitation

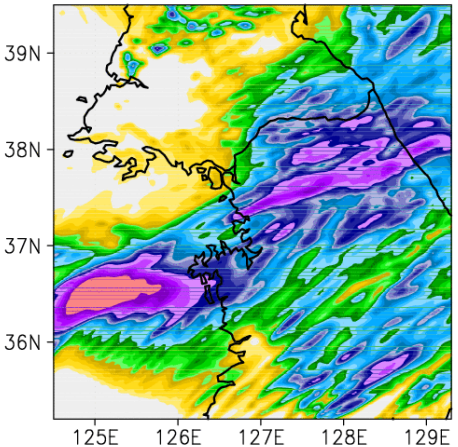
TMPA



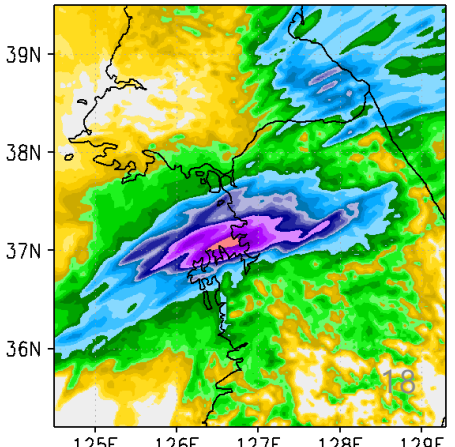
Original SAS in the domain with Δx = 3 km



No CPS in the domain with Δx = 3 km



Modified SAS in the domain with Δx = 3 km

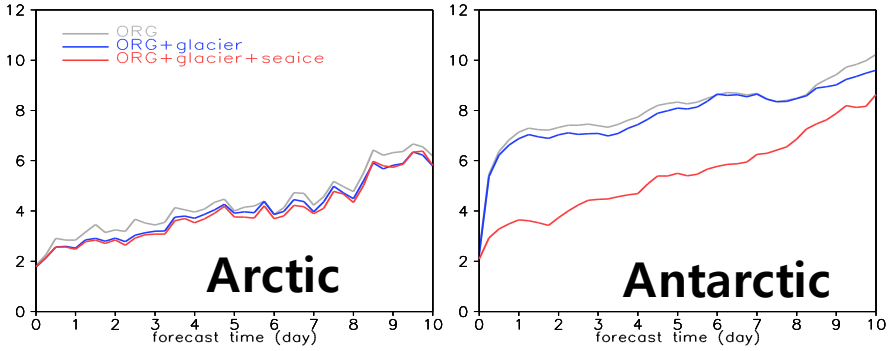


LSM

Advanced Physics

➢ Upgrade in Noah LSM

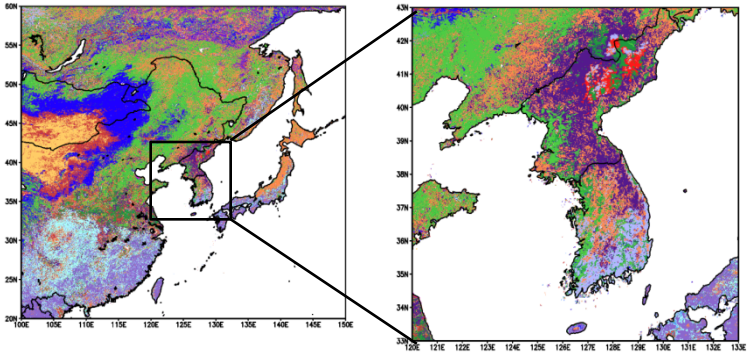
land	glacial-ice	sea-ice
Noah v2.7 (Ek et al. 2003)		OSU (diagnostic)
Noah v3.4.1 (as of 2012)	glacial parameterization	3-layer model (Winton 2000)



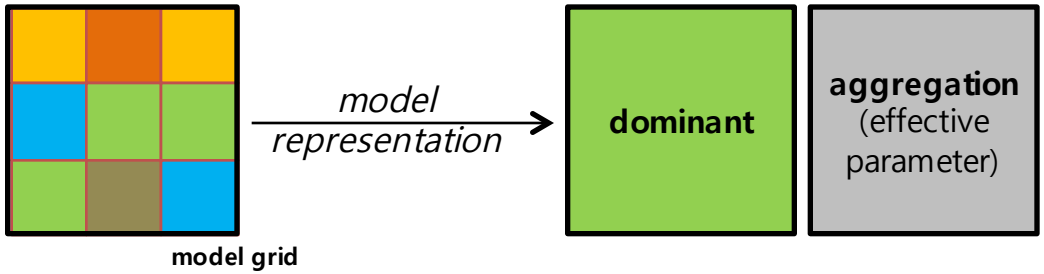
➢ Use of high-resolution surface data

Variables	Data
Land use	1-km modified IGBP (MODIS)
Soil texture	1-km STATSGO/FAO
surface albedo	0.05° MODIS MOD43C surface albedo
snow albedo	**0.05° maximum albedo for snow-covered land**
lea area index	**0.083° 30+ year climatology (LAI3G)**
displacement height	**0.083° canopy height (NASA)** in preparation

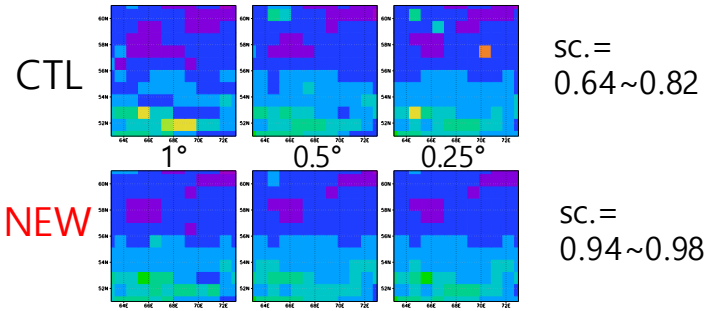
IGBP land use



➢ Parameterization of land-surface heterogeneity



Impact on Bowen ratio



Development Data Assimilation Systems

KPOP (KIAPS Package for observation processing)

Observation data preprocessing and data assimilation system-I

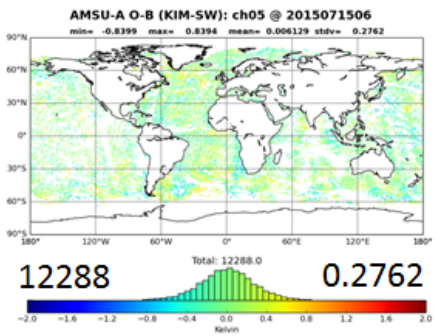
Incoming obs. data monitoring system and advanced quality control method

- AMSU-A: Bias correction coeff. Improve thinning method
- GPS-RO: Add geopotential height correction and vertical thinning method
- IASI: Build routines of removing cloud effect and iterative method for BC coeff.

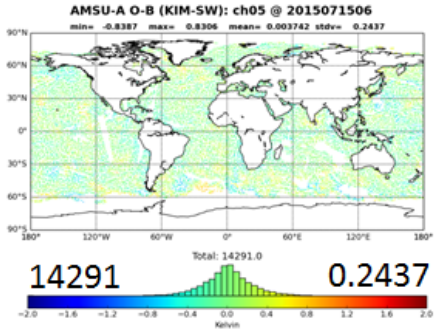
At the end of 2016, almost all the satellite data will be processed via KPOP

- KPOP: Construct the real-time incoming data monitoring system

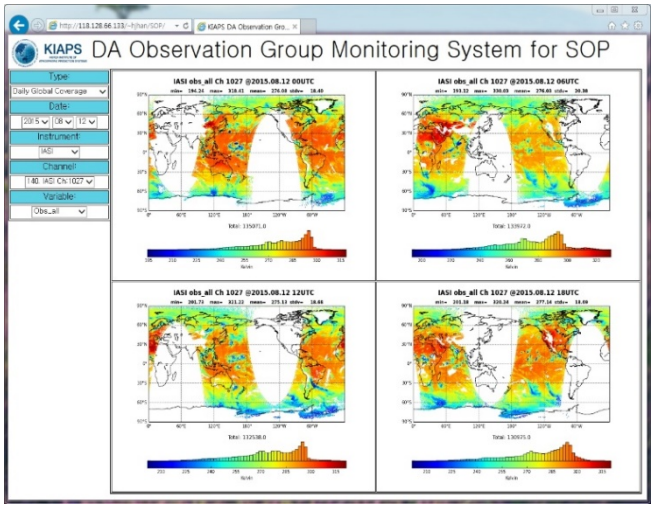
dist_weight (org)



omb_weight (thin_1.5)



Left: Original thinning method
Right: Revised thinning method
– more data and smaller standard deviation



Observation data monitoring system

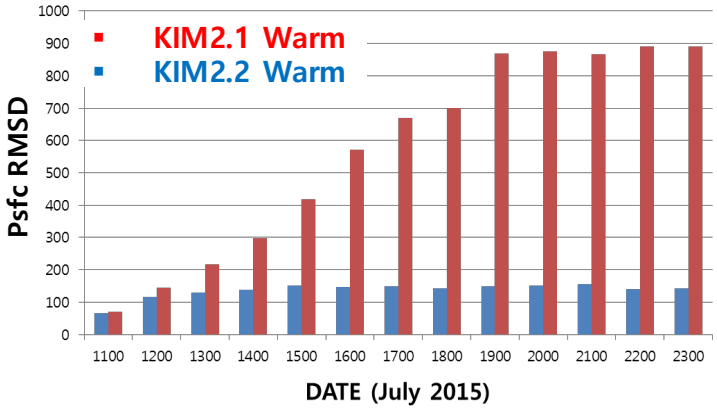
Observation data preprocessing and data assimilation system-II

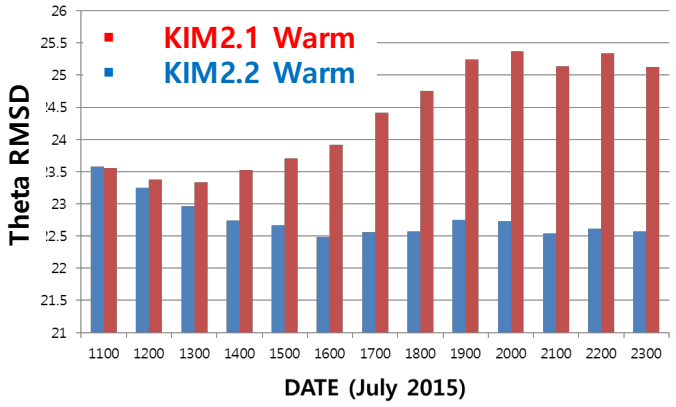
Development of 3DVAR data assimilation system for KIM

- 3DVAR system assimilating realtime observation data
  - The observation data for KIM 3DVAR system so far

Sonde, Surface, Aircraft, AMSU-A, GPO-RO, CrIS, ATMS, AMV, IASI

- Continuing improvement of the KIAPS 3DVAR system
  - Improving computational efficiency by spectral transform algorithm
  - Improving 3DVAR performance with better back ground error covariance



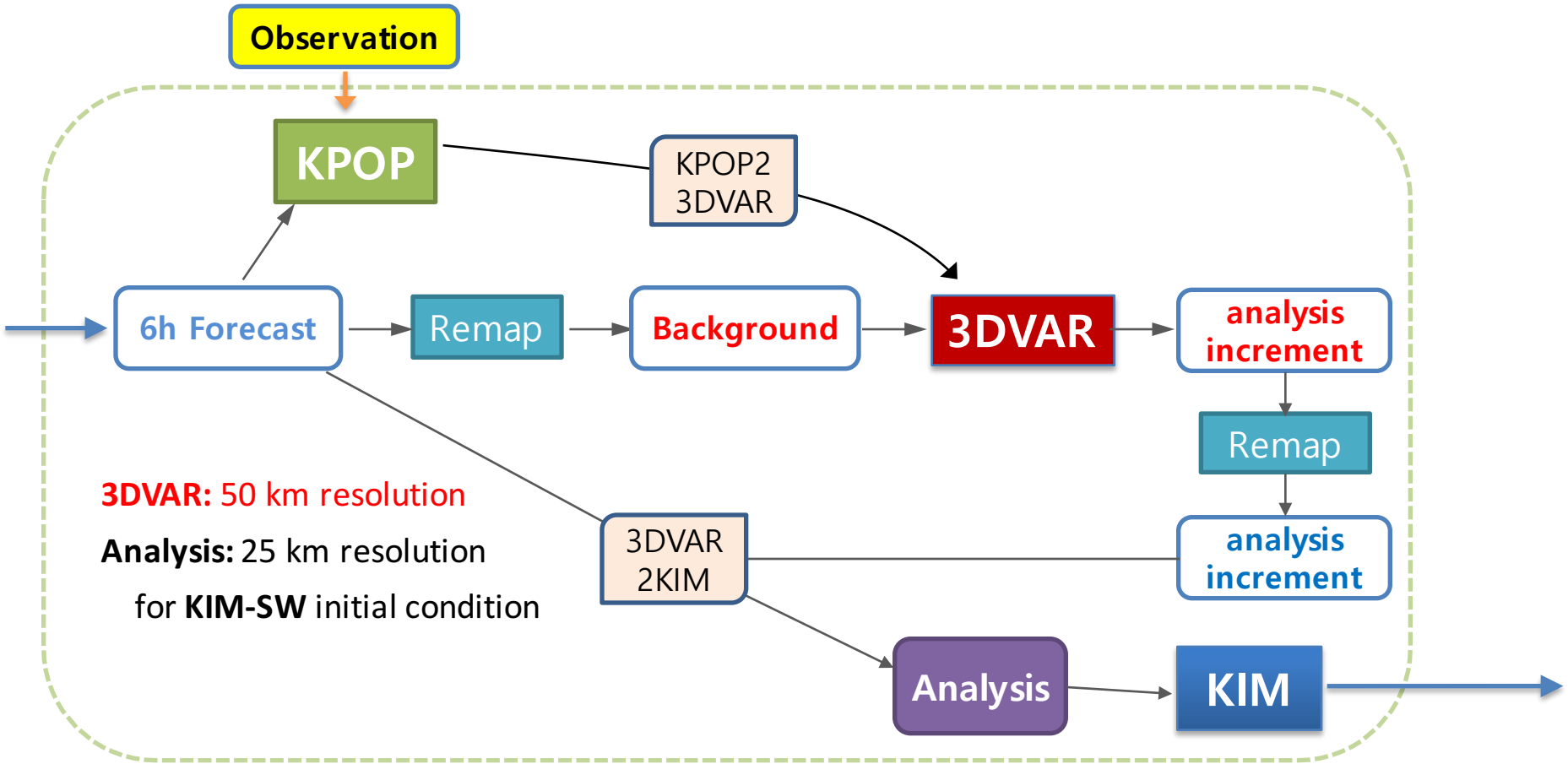


Song and Kwon (2014)

RMS difference between KIM 3DVAR and UM analysis data (left: Psfc, right: theta)

Semi-Real time Cycle

- Development of 3DVAR system for hydrostatic/non-hydrostatic model
  - Modification to fit **KIM-SW** (non-hydrostatic model)
- **Flow chart of cycling system (Warm cycle)**

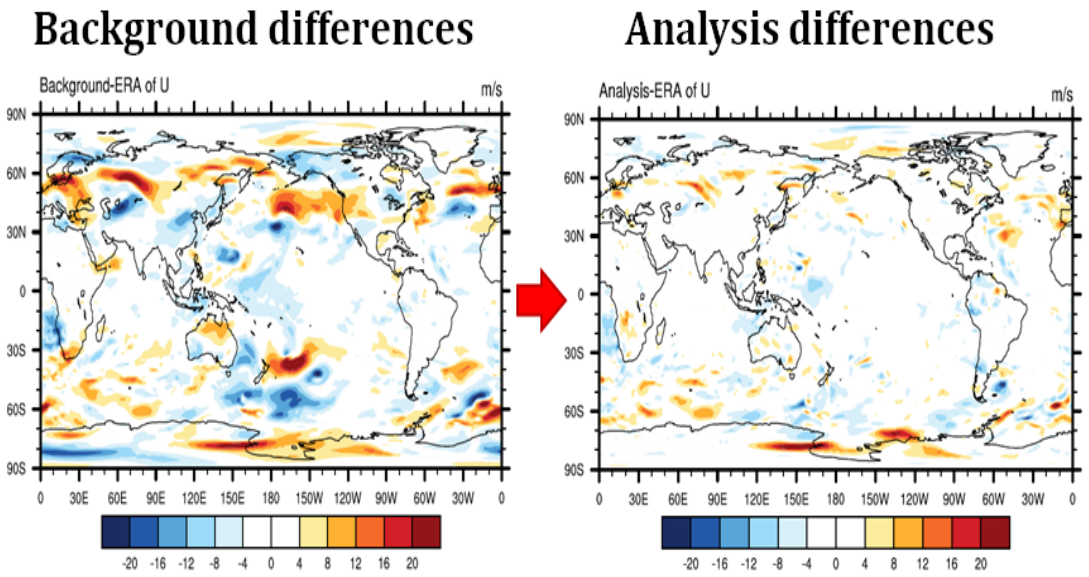


Observation data preprocessing and data assimilation system-III

Development of LETKF-KIM ensemble DA system

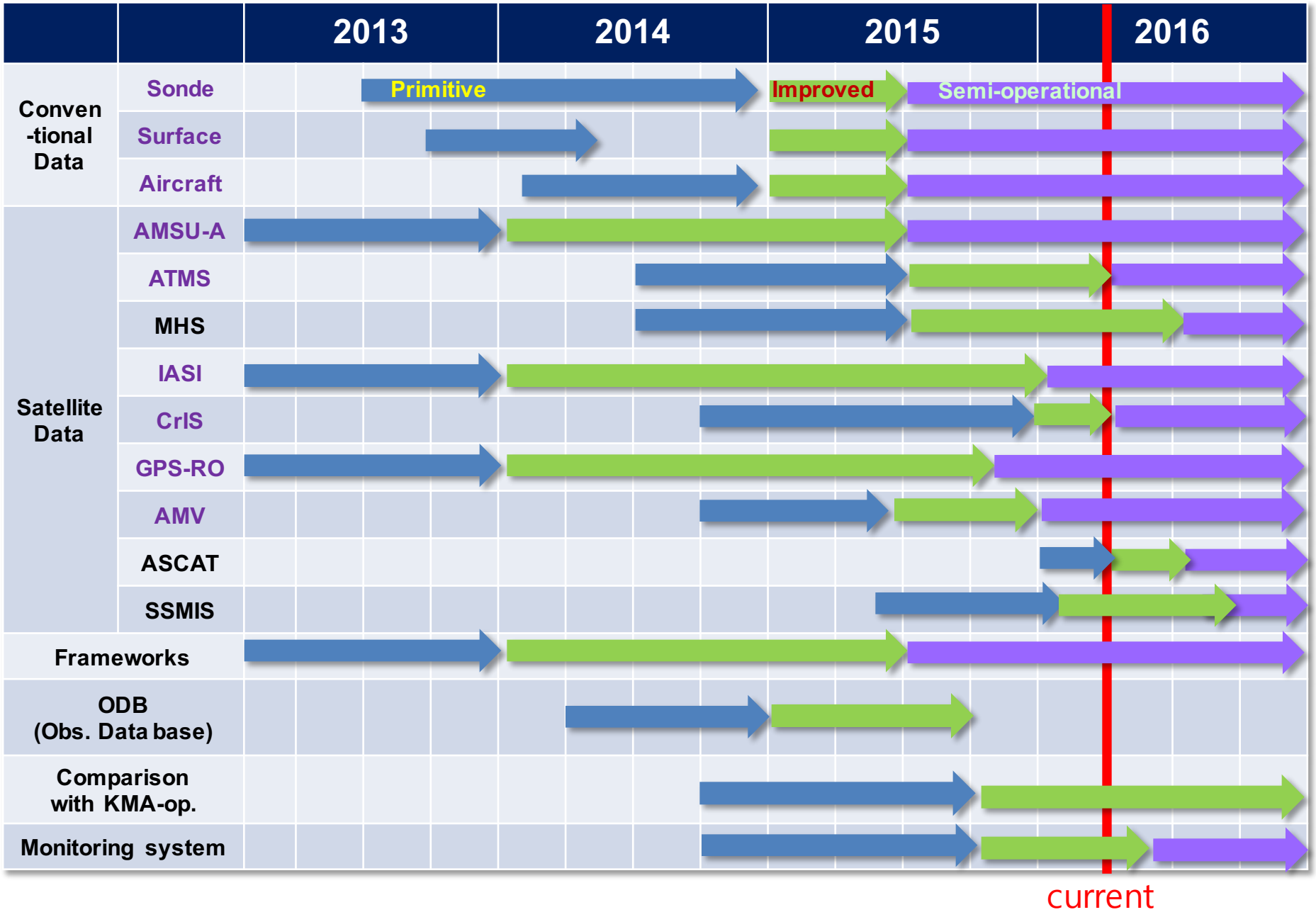
- Assimilating real observation data after idealized tests
- Improvement of additive/multiplicative inflation to enhance the performance
  - The observation data assimilated so far

Sonde, Surface, AMSU-A, GPO-RO

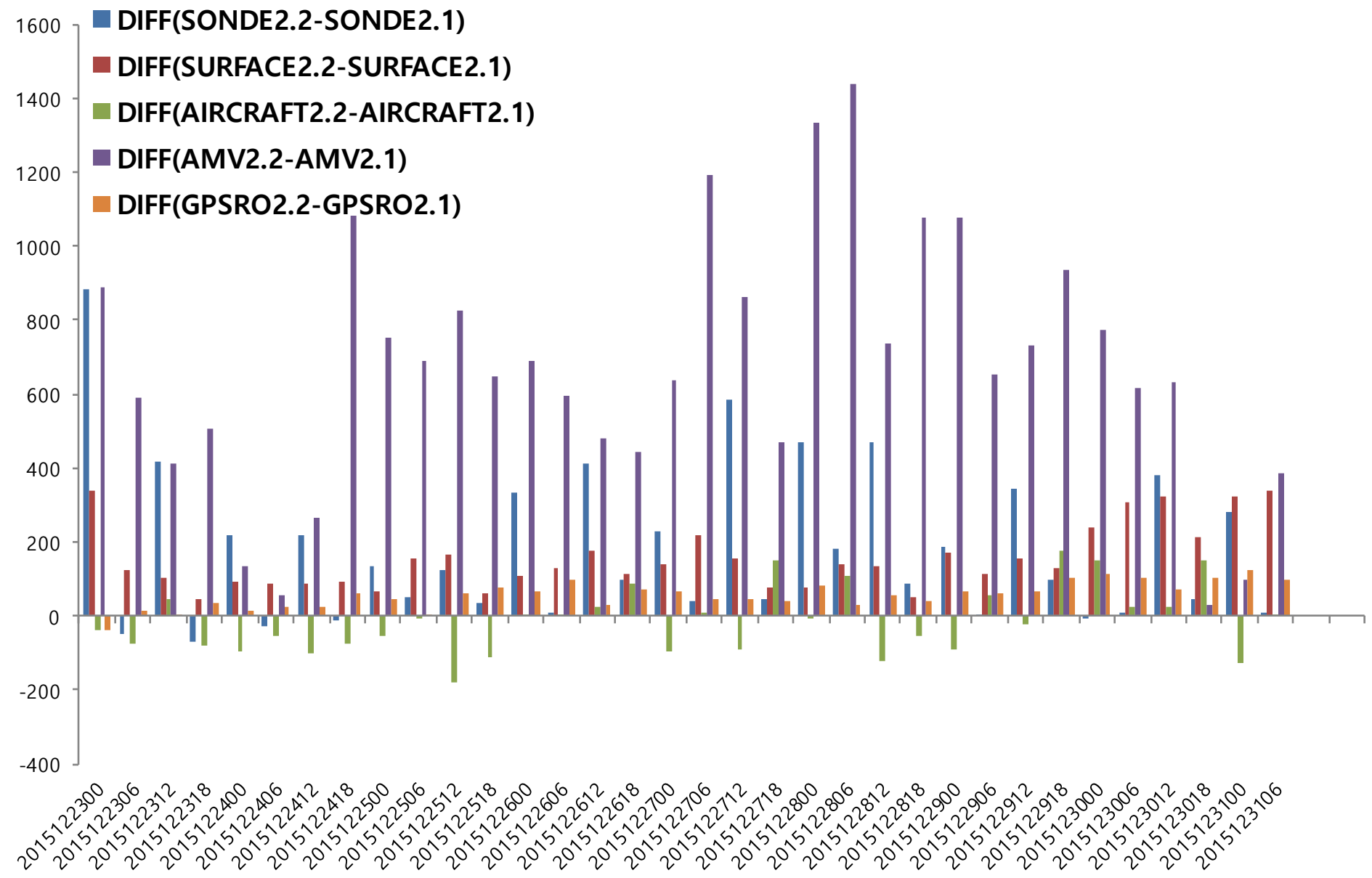


RMS difference of 925 hPa zonal winds compare to ERA-Interim data

Observation data



The difference of obs. data assimilated KIM (v2.2-v2.1, positive means more data for v2.2)



System Optimization

Software Framework

Computational efficiency

- Change Entire → **Unique** :
- Apply the **PNetCDF** :
- Apply the **IO decomposition** :

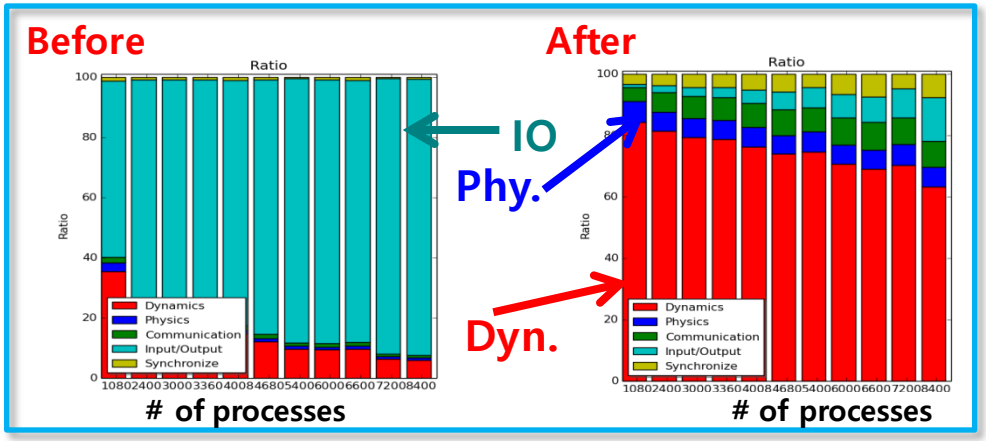
IO Improvement

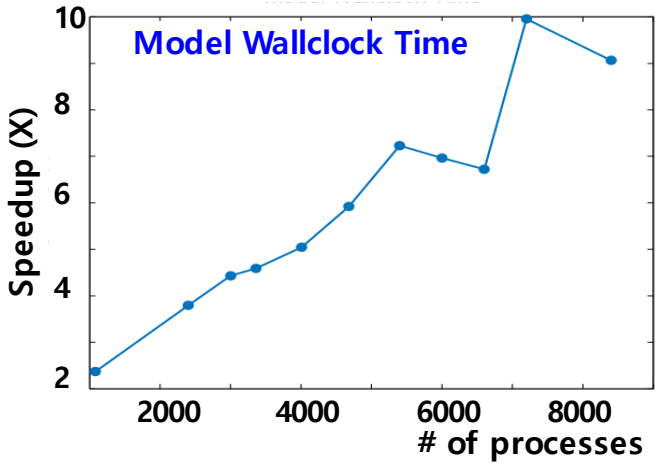
x2

x25

x2

} x108 → Model wallclock ~ x10





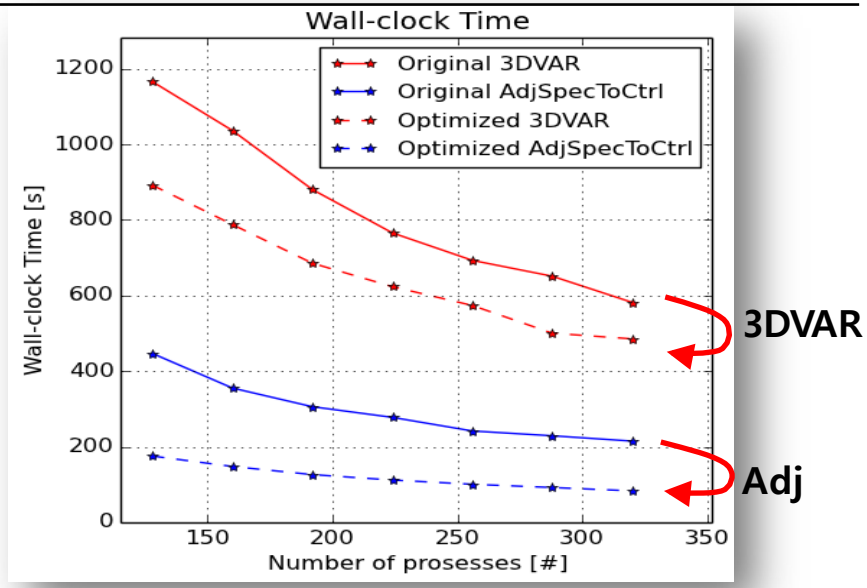
- **KIM Profiling (v0.26.04)**
  - Model wallclock time
  - 10 day forecasts
  - △t = 30, 15 sec

	ne60 (50 km)		ne120 (25 km)	
core	2400	5400	2400	**5400**
SH + GPPACK(3.3)	1:09	0:38	8:12	**3:57**
SW + GPPACK(3.3)	1:35	0:53	11:19	**5:27**

Software Framework

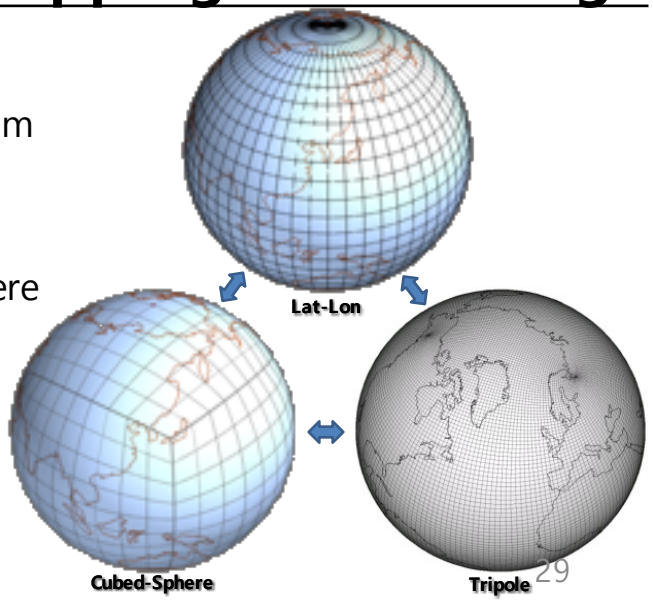
- **Install 3DVAR in the Framework**
- **Optimization**
  - Rearrange the 3D arrays in AdjSpecToCtrl routine
  - Remove the reproducible-sum routine

Optimization in Parallelization



Remapping Tool Package

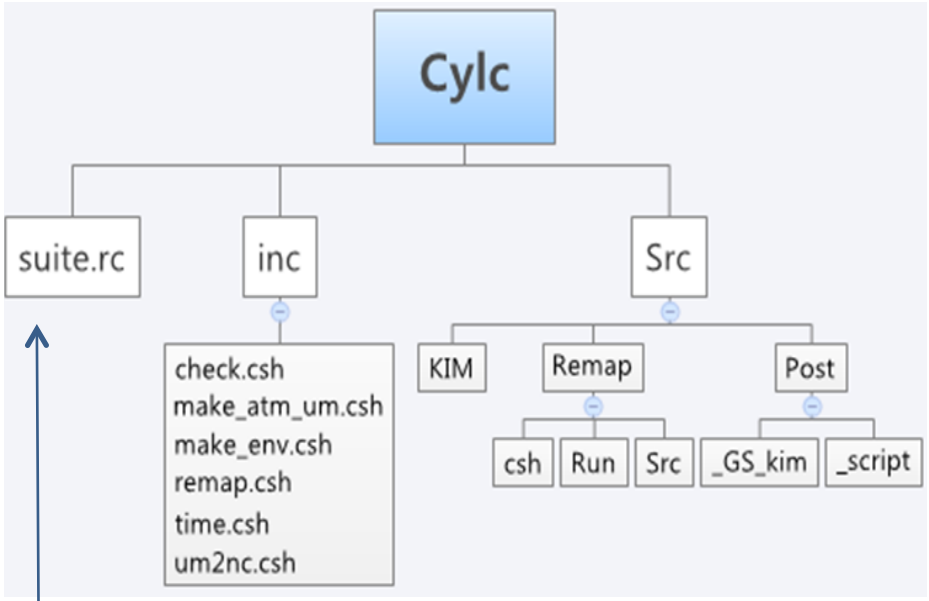
- **V-GECoRe**
  - Geometrically Exact conservative remapping with Voronoi diagram
- **Lagrange interpolation**
  - 3rd-order interp. in a element, the most effective for cubed-sphere
- **Bilinear interpolation**
- **Nearest**



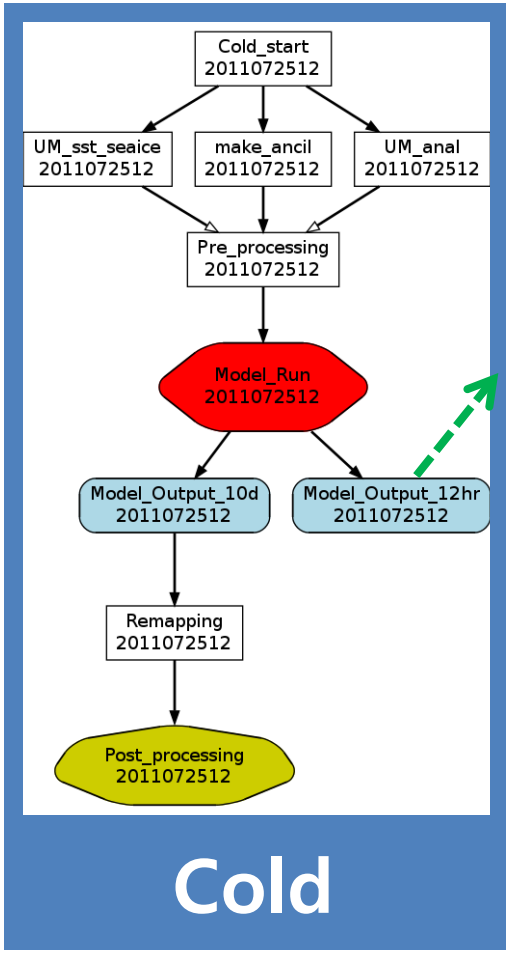
Software Framework

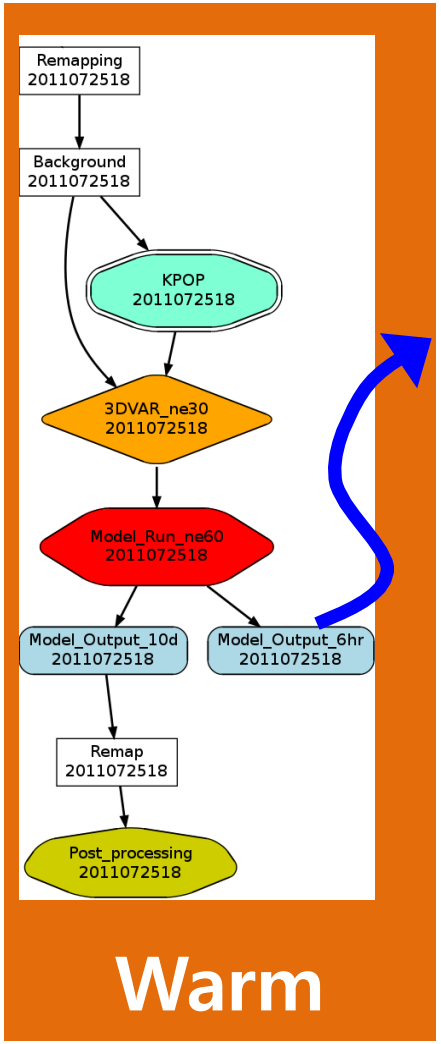
Job scripts

- **Cylc scheduler**
  - A meta scheduler to control the complex tasks efficiently
  - Possibility of setup, modification and monitoring user-friendly



- Run with the suite.rc
- type (1:cases, 2:mid-term, 3:cold, 4:warm)
- initial/final cycle time





Verification

Verification

Testbeds

Model

Resolution

Testbeds

KIM (KIAPS Integrated Model system)
reference models (GRIMs, WRF)

100 km (~T126/NE30) to 25 km (~T510/NE120)
50 levels, top ~ 0.3 hPa

High-impact weather forecast

- Heavy-rainfall event
- Heavy-snowfall event
- Migratory cyclone event
- Typhoon Bolaven and Tembin
- Typhoon Sanba

Seasonal simulation

- 2013 JJA, 2013-2014 DJF
- T126L28
- 5 ensemble members

Medium-range forecast (10-day forecast)

- **cold start** for July 2013, February 2014

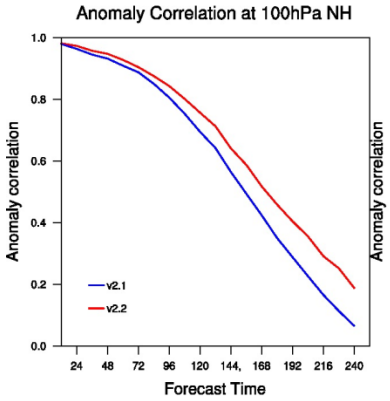
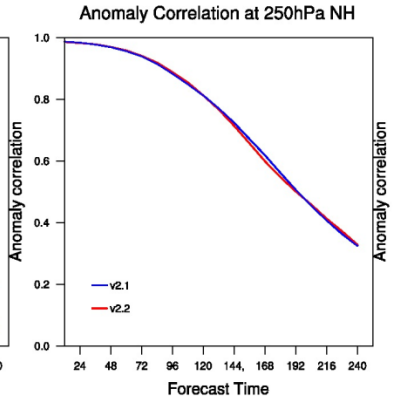
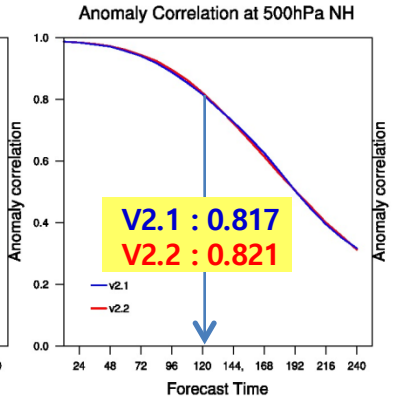
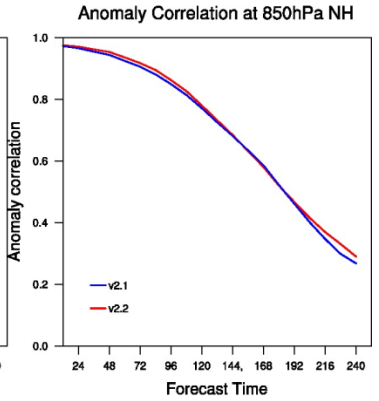
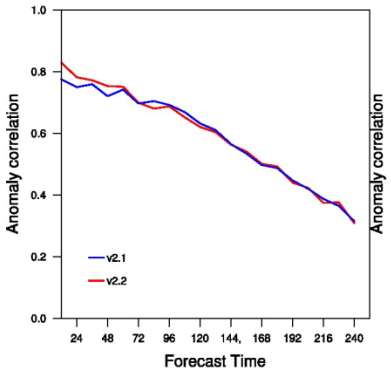
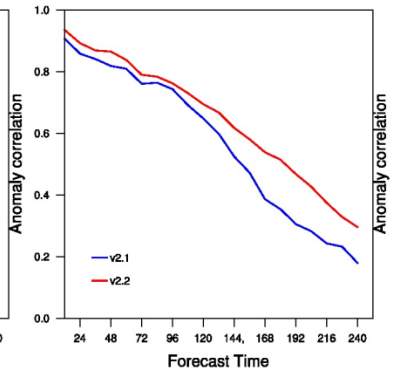
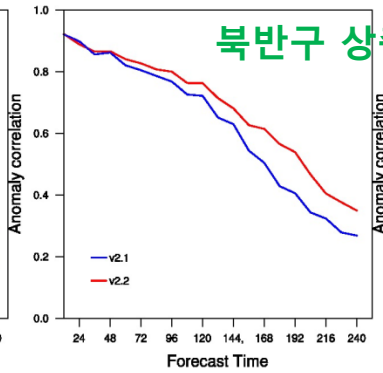
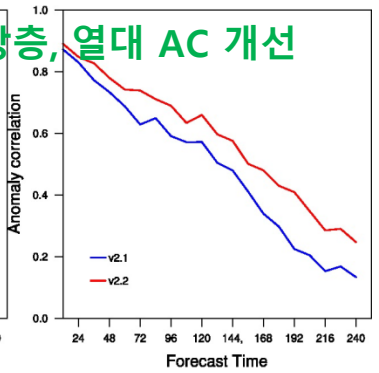
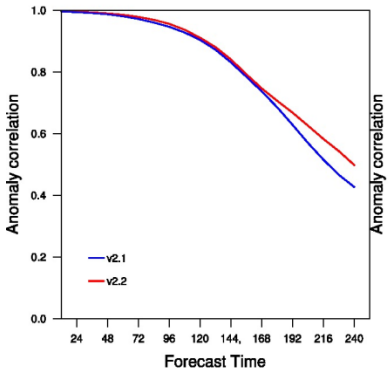
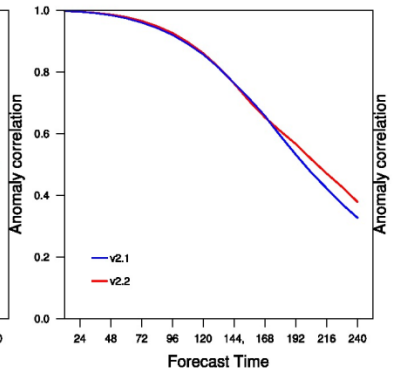
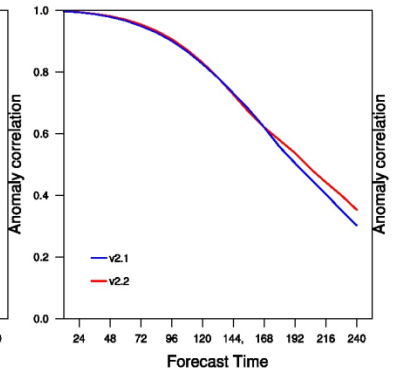
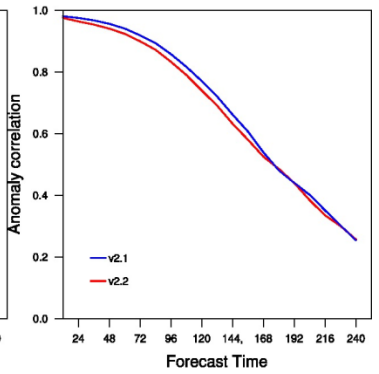
Semi-real-time

- **warm start** since 1 July 2015

: v2.1
: v2.2

HGT: AC

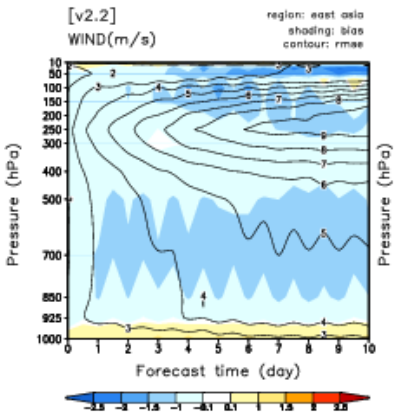
20130701-31 (NE60, 240hrs)

	100 hPa	250 hPa	500 hPa	850 hPa
NH				
TR				
SH				

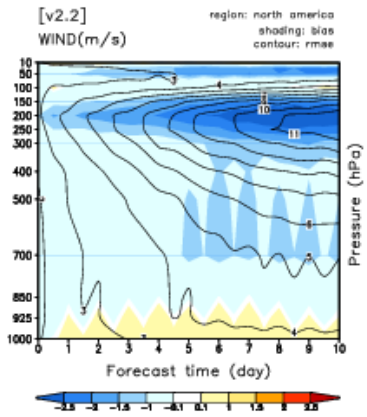
WIND

20130701-31 (NE60, 240hrs)

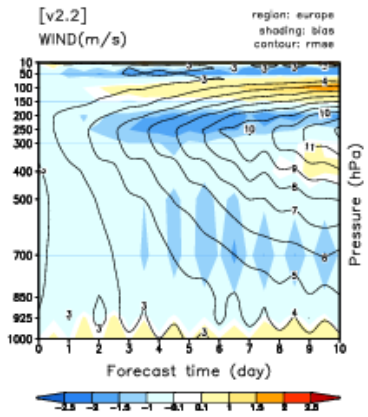
V2.2



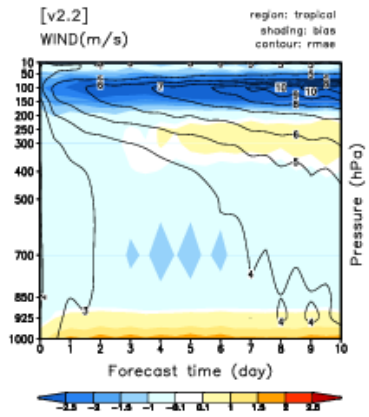
EA



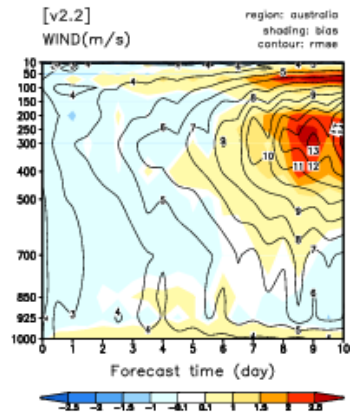
NA



EUR

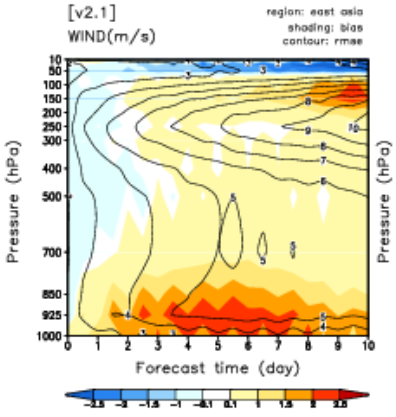


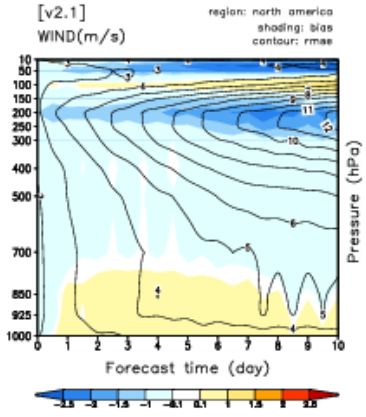
TROP

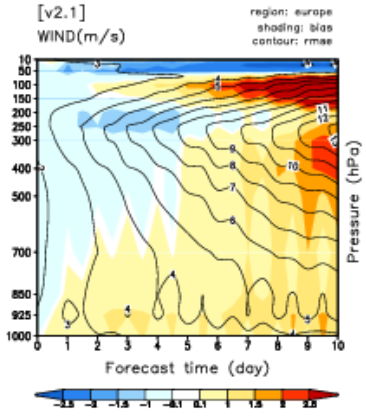


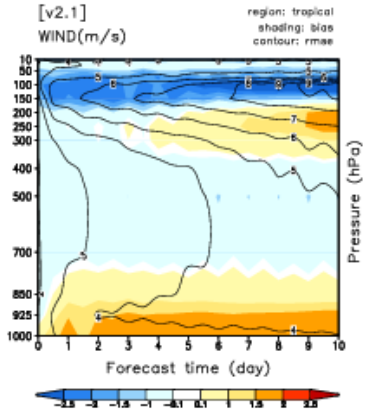
AUS

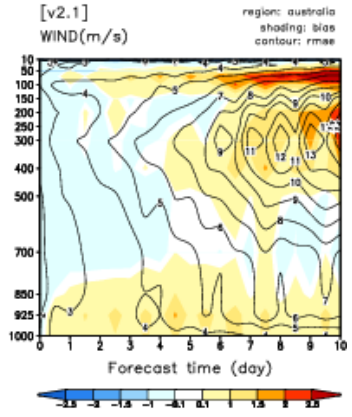
V2.1



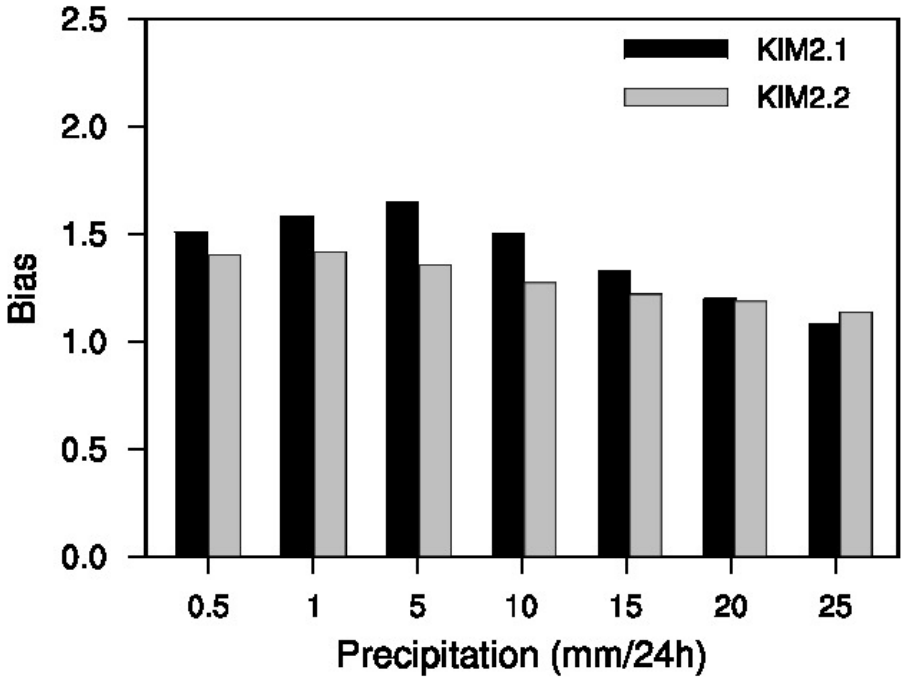


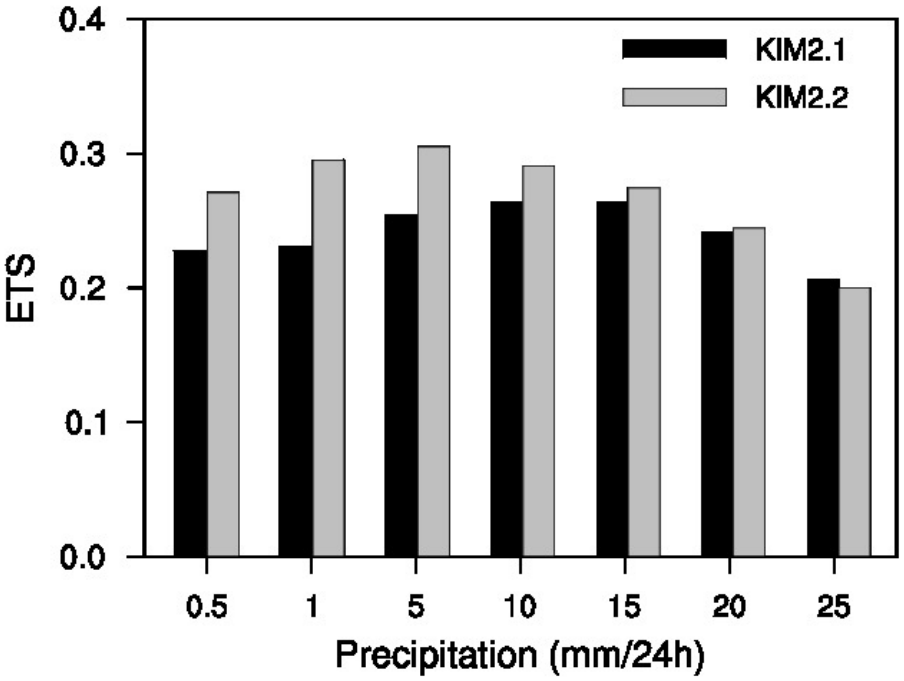




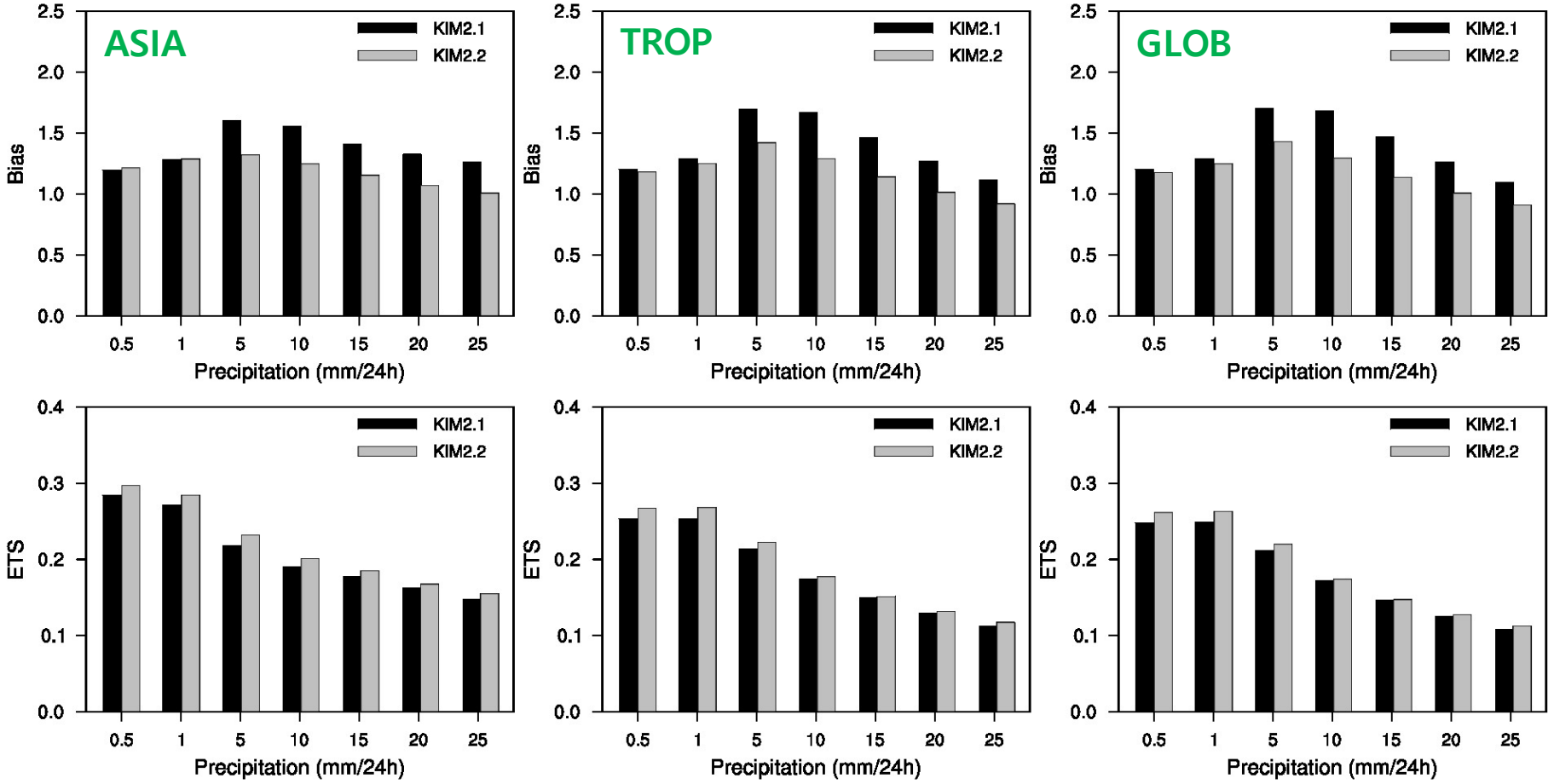


강수전반 감소, ETS 증가





3-day average of 24-h accumulated precipitation



강수전반 감소, ETS 증가

3-day average of 24-h accumulated precipitation

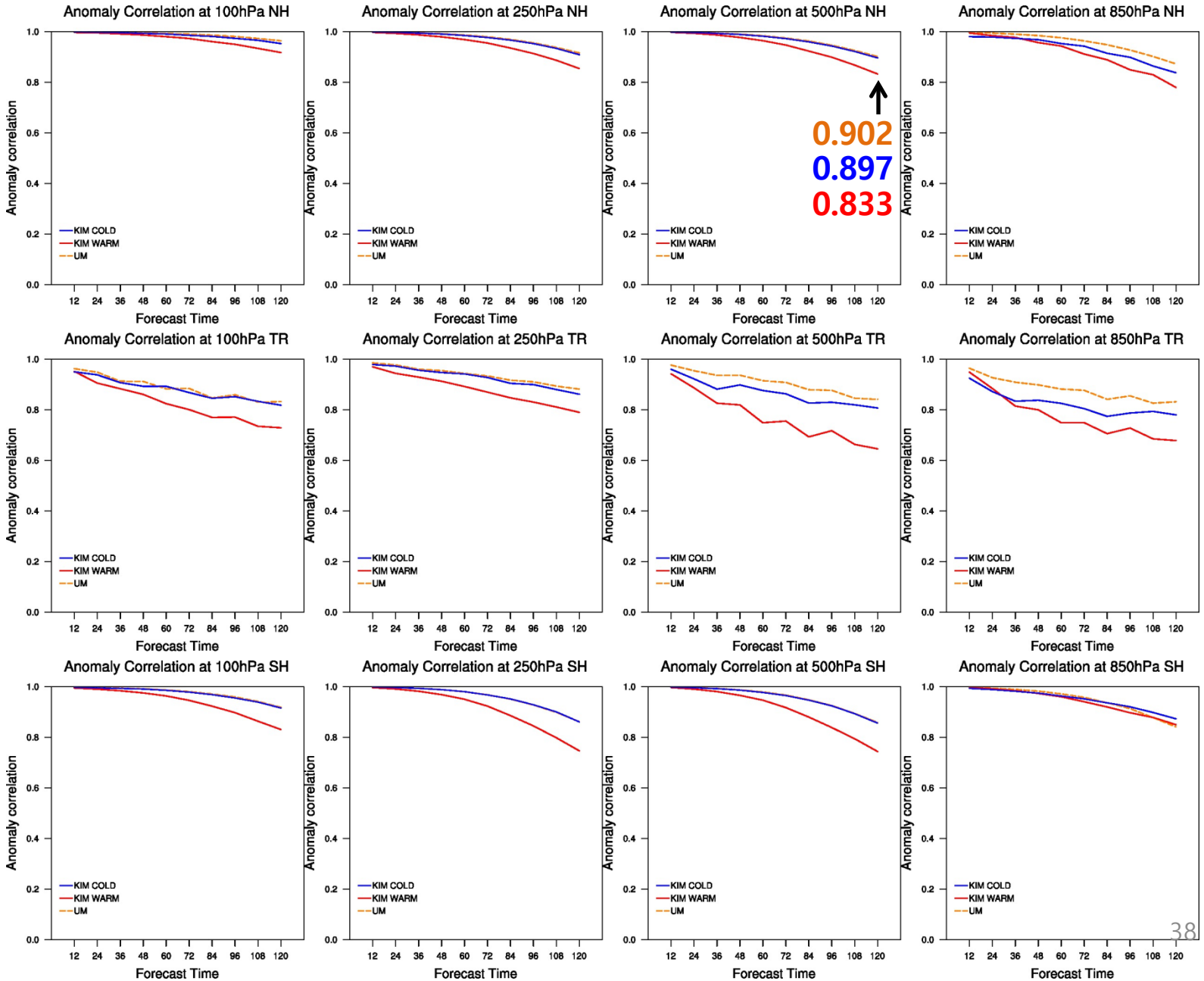
Verification results of semi-real run (2016. 2)

Anomaly Correlation of geopotential height

NH

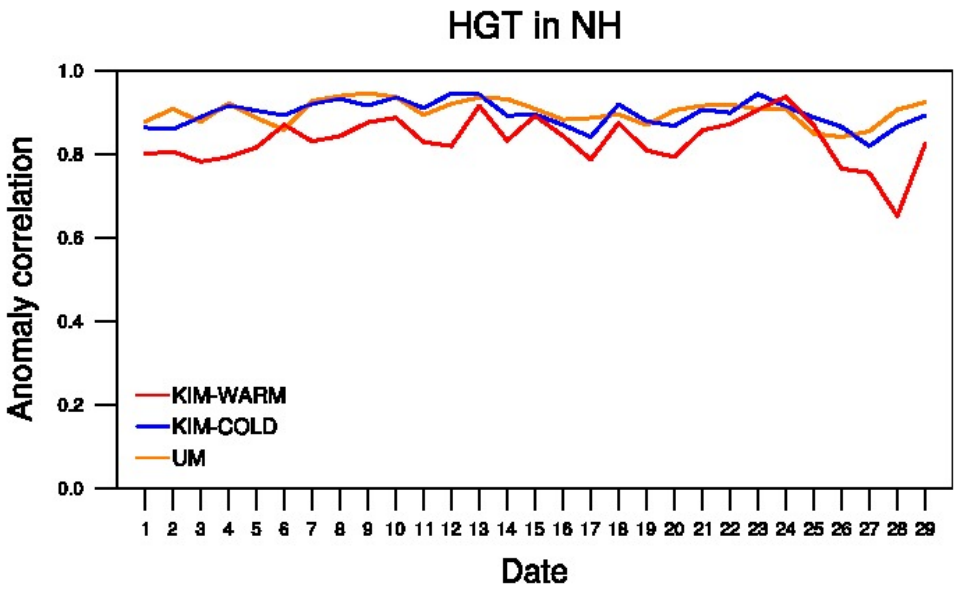
TR

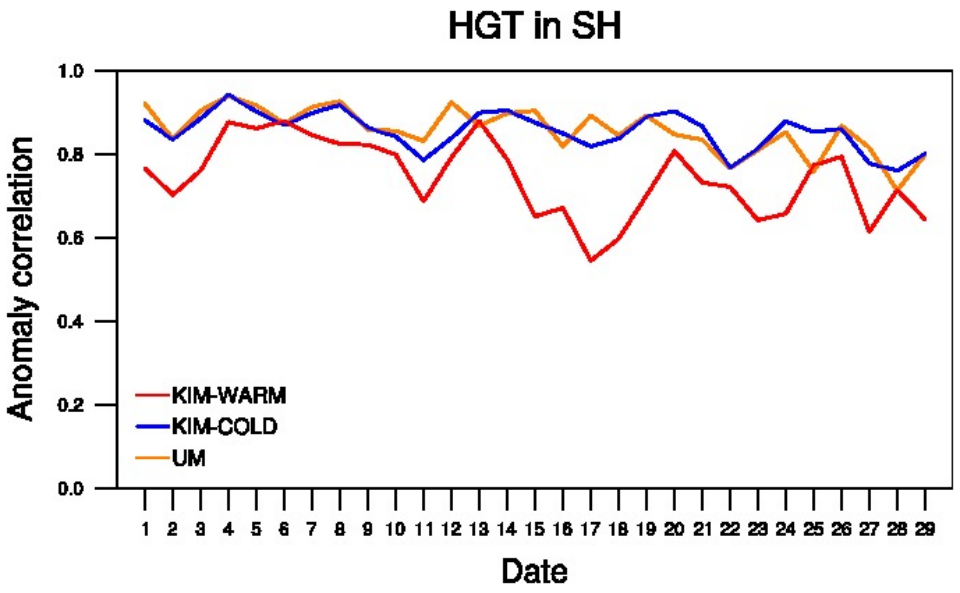
SH

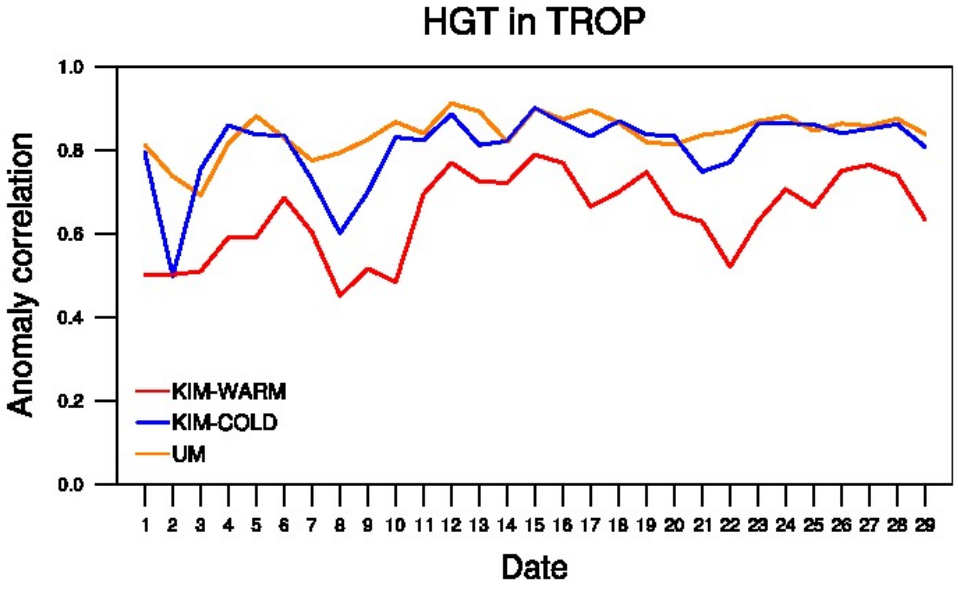


검증스코어 모니터링: 일별

HGT 500 120 fcst hour AC

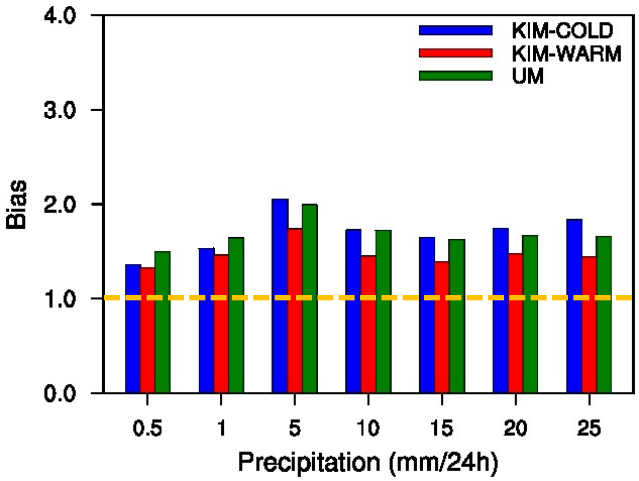


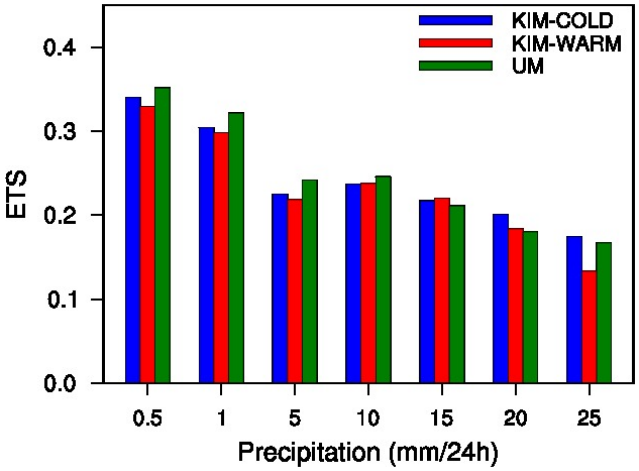




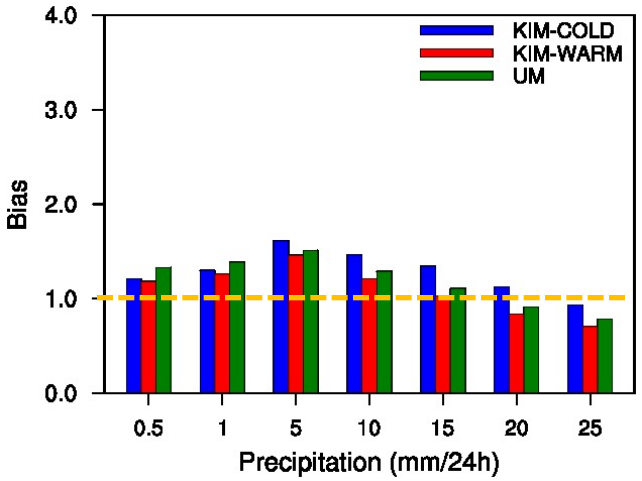
Verification for rain (CPC)

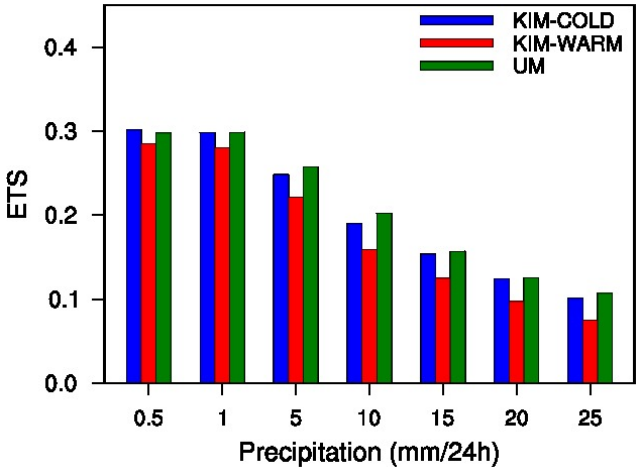
ASIA



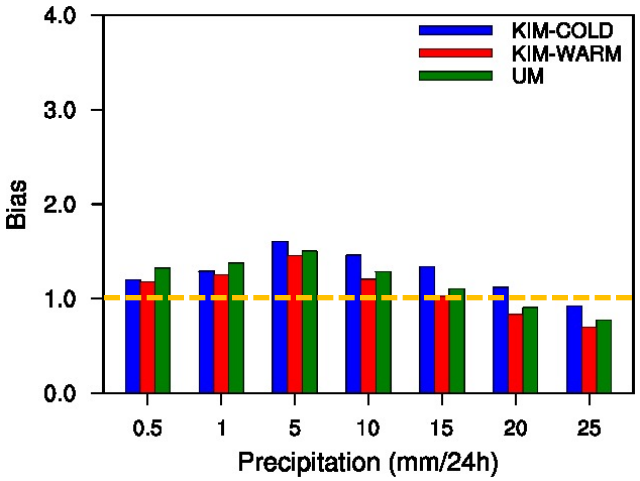


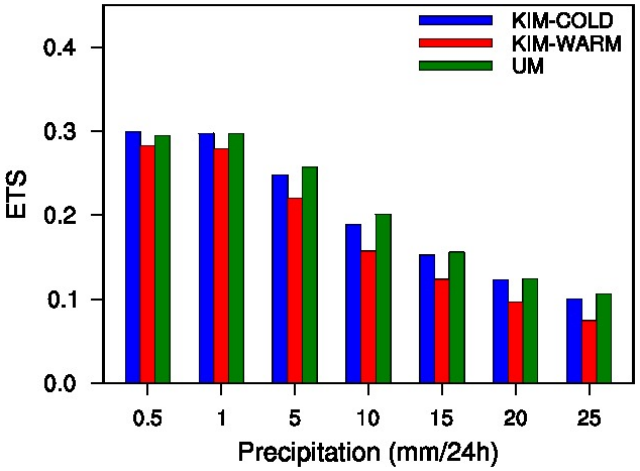
TROP





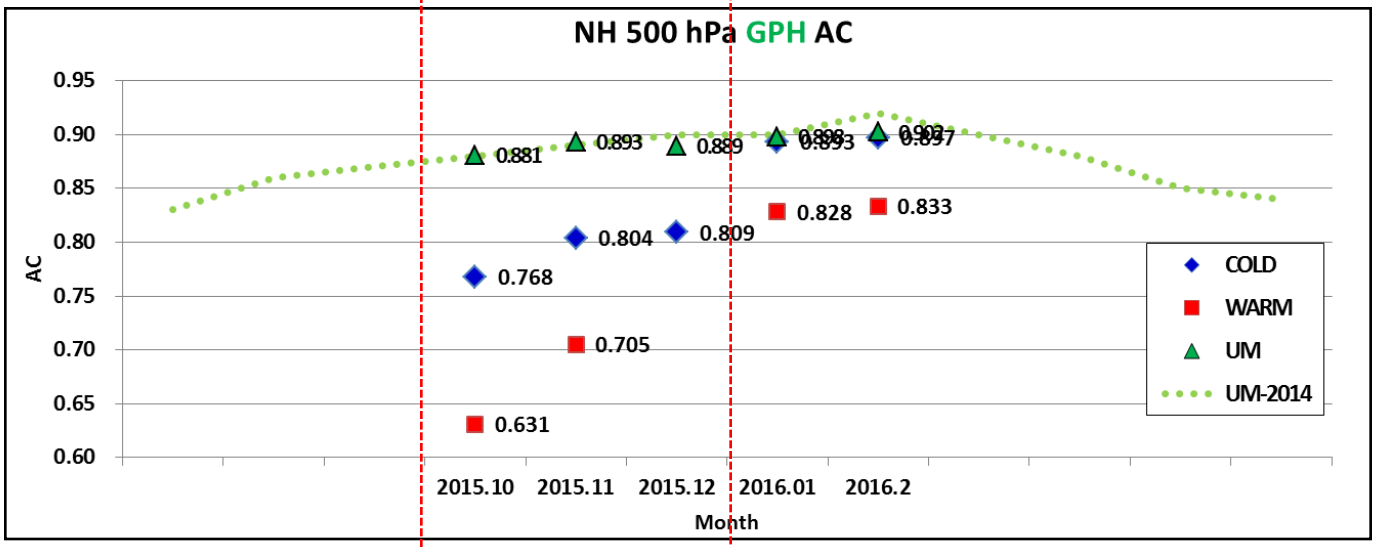
GLOB



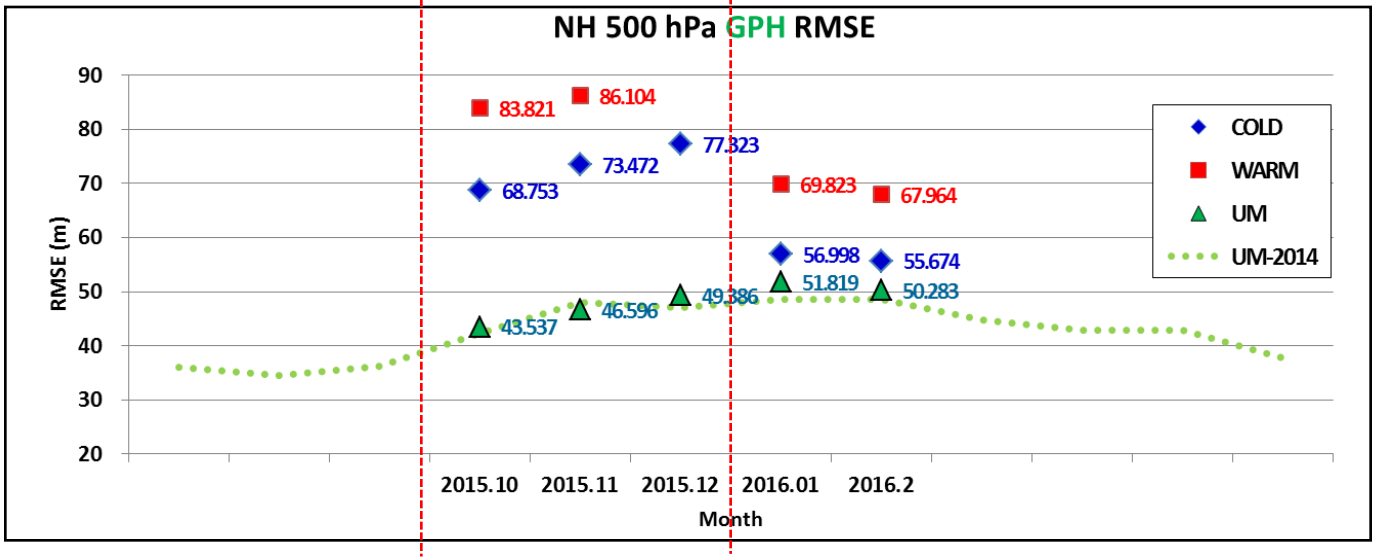


월별 준실시간 검증 스코어

북반구
500 hPa GPH
AC

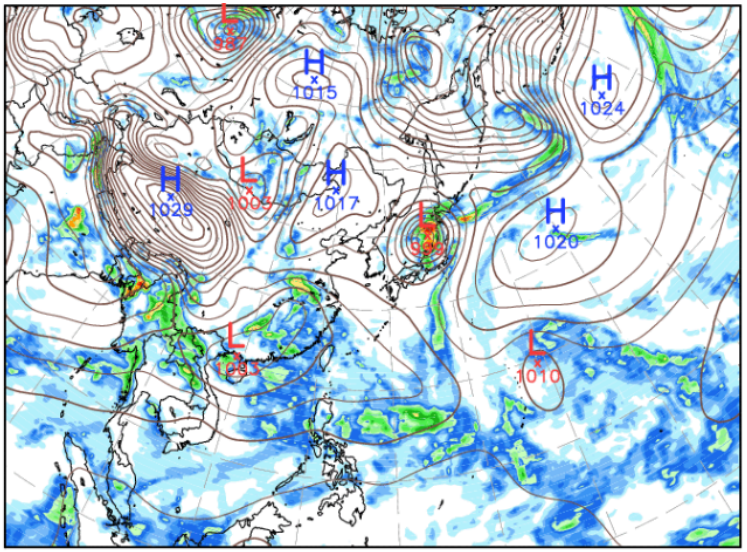


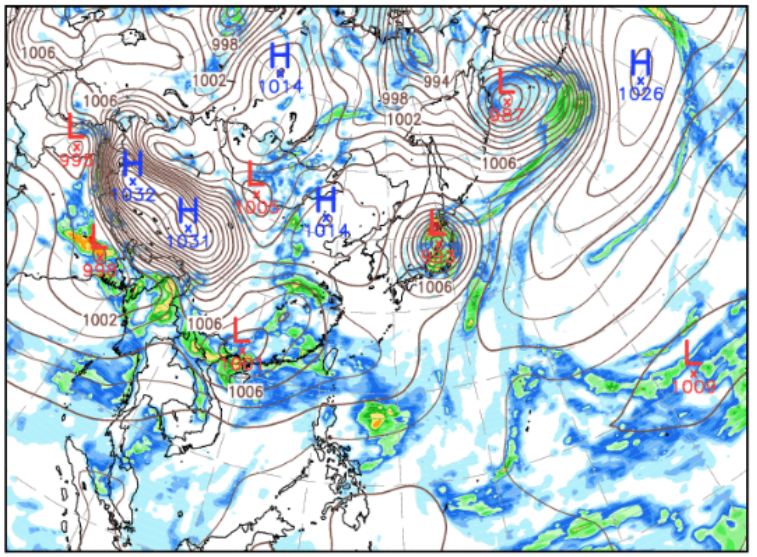
북반구
500 hPa GPH
RMSE



KIM Semi-real-time 2015.7.13.00 UTC(+120hr fcst)

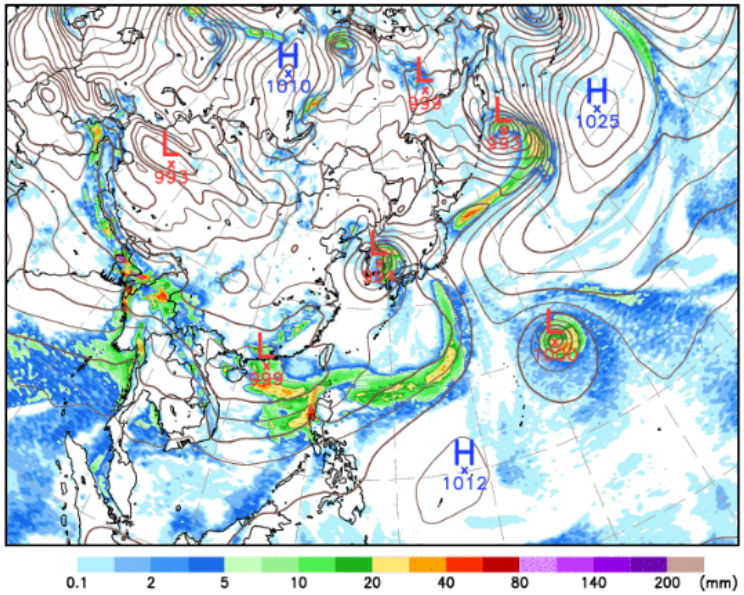
COLD

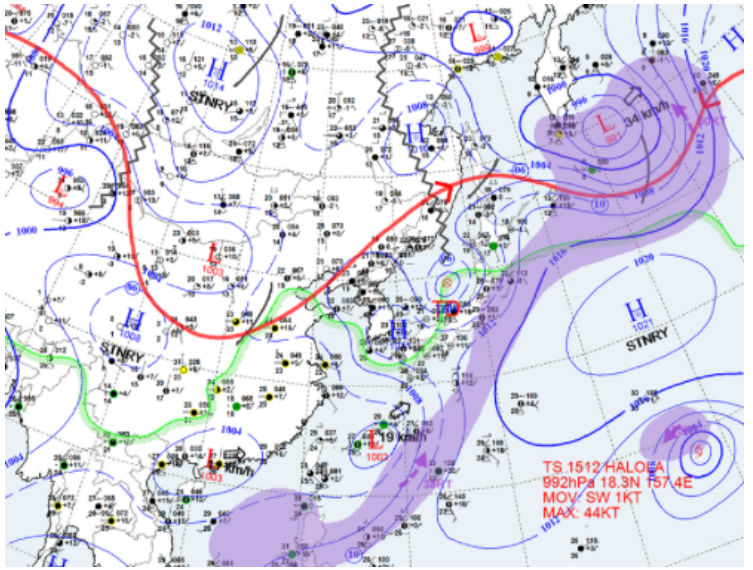




WARM

UM





OBS

Shading: 6hr Accumulated Precipitation (mm)
Contour: Mean Sea Level Pressure (hPa)

2016 Plan

	2.2 (JAN 2016)	2.3 (APR 2016)	2.4 (JUL 2016)	2.5 (OCT 2016)
Dynamic		· High order diffusion · Hybrid vertical coordinate	· complete standard dynamic core · prepare dx=10km dynamic core	· start dx=10km dynamic core
Physics	· climatology data for physics package · Update physics package	· Minor bug fix of v2.2 · Complete standard physics package	· develop advanced physics package	· Complete advanced physics package
Data Assimilation (3DVAR / LETKF)	· IASI, AMV (85 %)	· ATMS (temperature), CrIS (90 %)	· ATMS (moisture), MHS, CSR (95 %)	· ScatWind, SSMIS (100 %)
	· Improve background error covariance	· High analysis resolution (50 km)	· 4D Hybrid EnVAR	· High analysis resolution (25km)
	· Conventional, AMSU-A, GPS-RO (80 %)	· Conventional, AMSU-A, GPS-RO, AMV (85 %)	· IASI (90 %)	· CrIS, MHS (95 %)
	· Coupled with KIM v2.1	· Initial semi-real time version	· Improve ESV	· Optimize ESV
System	· Update surface cycling · Update ancillary data	· Rotate cubed sphere grid · Spectral filter topography	· Update KIM framework · Code clean up and standardization	· Develop KIM-API · Develop KIM coupler
Verification	· Verification of physics package · Verification of semi-real time KIM	· Standard verification system (KAT-STAT) · Verification of semi-real time KIM	· Standard visualization tools (KAT-PLOT) · Verification of semi-real time KIM	· Verification of semi-real time KIM

* ESV : Ensemble Singular Vector
* API : Application Programming Interface